Myopia Manual

Edition January 2022

Changes since the last update January 2021 are marked in red

An impartial documentation of all the reasons, therapies and recommendations

Unbiased summary of the literature, some ideas about linkages between the various published results, and recommendations for shortsighted people and people who don't want to become shortsighted at all.

Dr. rer. nat. Klaus Schmid, Physicist

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Preface

Especially worth mentioning appears to be:

- That the **neurotransmitter Dopamine** has a substantial impact on the onset of myopia is already known since some years. Now more details of what has an influence on dopamine and its metabolism are appearing and first results of dopamine eye drops showed some promising results on animals.

- The primary systemic agent to prevent myopia, especially pathologic high myopia appears to be **vitamin D** by its positive impact on dopamine and oxidative stress in the eye.

- The color of the light to which the eye is exposed gets increasing attention: The blue, shortwave component of an illumination is reported to be protective, which explains the positive effect of time spent outdoor as well. Additionally, the bandwith of illumination appears to be important. On the other hand, LLLT (low level laser therapy) with red led light directed at the retina had a positive effect as well-

- Research being mainly focused on optical effects involving the retina, however, inflammation appears to play a significant role as well. Therefore means to limit the progression of myopia by limiting inflammation might be helpful.

- The negative effect of extensive accommodation on the onset and the progression of myopia is known since a long time. The life-experience ophthalmologist Viikari is, however, that in many cases an existing juvenile hyperopia is the basis of this extensive and harmful accommodation, which can be avoided by using plus lenses. This is especially important, as the developing eye of children is generally hyperopic. With the research world being set to explain myopia by a retina-image model, some practitioners explain myopia more by models based on mechanical forces and resulting degradation of connective tissue. The fact that accommodation generally causes a temporal elongation of the eye is mostly ignorded, and the attention of research is less focused on the origin of myopia – in most of the cases excessive accommodation – and more on how to cope with myopia.

- "People with **a certain variant of the gene** - called APLP2 - were five times more likely to develop myopia in their teens if they read for an hour or more each day as a child. … those who carried the APLP2 risk variant but spent less time reading had no additional risk of developing myopia."[1078] This means simply not myopia is inherited, but the sensitivity with respect to environmental conditions.

- Some unspectacular but maybe helpful result is the positive impact of making the children to go to bed early at night and to avoid long time nearwork in the evening and on weakends.

- A solitary but promising report is the successful use of **LLLT (Low-Level Laser Therapy)** against progression of myopia and maybe even for the reduction of myopia.

- Tables might be helpful, where **the success of various interventions against the progression of myopia were evaluated** (section 3.27).

Disclaimer

This book is intended as an informational guide to be used as a supplement, not a substitute for professional medical advice. While the information and advice in this book is believed true and accurate, the author cannot accept any legal responsibility.

Acknowledgements

This book is an effort to put pieces of the myopia puzzle together. These pieces were found in numerous books and scientific publications, and therefore I am extremely grateful to all these professionals for their work and their sharing of their results.

Additionally, quite a number of readers of the Internet version of this book helped with very constructive, encouraging and competent comments.

Finally, thanks to my son Bernhard Schmid who was very helpful by taking care of all the data processing problems, which had to be solved to complete this book.

This book is dedicated to my wife Veronica
and my children Nadine and Bernhard,
whose shortsightedness caused me
to write this book.

Hopefully it will be helpful not only for them.

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Introduction

The Situation - and the Target of this Book

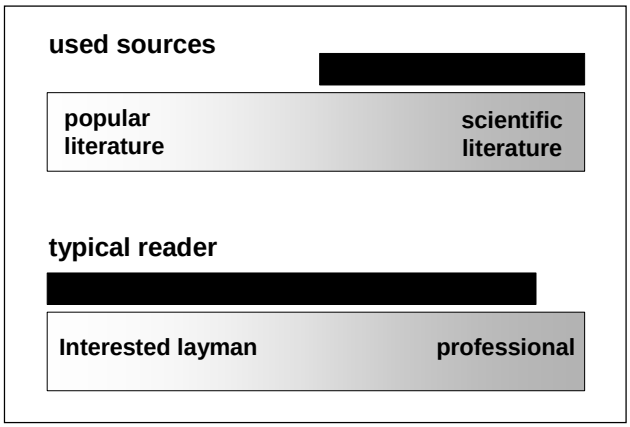
Old-fashioned traditional medicine stated that myopia is an inherited condition and the only solution is to prescribe glasses. People who objected to this "therapy" (it's not really a therapy, but only a short term covering of symptoms) were treated as ignorant.

In many papers, however, it was reported that today very many people are becoming myopic even though their parents or grandparents were not. On the other hand, life today is very different from that of our ancestors – just to mention the changed working environment and changed nutrition. Therefore, it is rather obvious that these changes in the environment have an impact on the incidence of myopia. Definitely, some people are more sensitive to these changes than others – by heredity.

If we can map all these negative influences and understand how they are affecting myopia, then we have a chance at minimizing myopia in some, decreasing its progression in others and in some cases, preventing it altogether. At the very least, we may be able to minimize the very serious consequence of blindness.

The idea of finding just one mechanism for myopia and solving this problem once and forever is very tempting, and some authors give the impression that they are close to this goal, and that all the other researchers, optometrists and ophthalmologists are wrong. Strangely enough, these authors often disagree with each other. The conclusion is not that some researchers are right, and of the rest of the researchers are wrong – all of them are right in their specific view of their experiments and experiences. Clearly, various different mechanisms exist that can lead to myopia. It is more important to find commonalities in the results than the contradictions.

Moreover, a long chain of processes (e.g. genetic, biochemical, environmental, nutritional) can cause myopia (like many other medical problems), and therefore very different interventions targeting these single processes can be successful.



Unfortunately, it appears that too little financial resources are available for research in myopia, since the industry financially benefits from the existence and progression of myopia than from its prevention. Just one number: In 1993 the USA spent 3.4 billion $ US on optical correction of myopia[1]. Definitely, the number is substantially higher today – not counting the personal inconvenience, the inability to work in a planned profession, and the suffering because of the

permanent progression of myopia: in some countries myopia is the first or second leading cause of blindness[2].

I will outline numerous essential results reported by researchers and practitioners. Since I have no personal involvement, i.e. no personal results to promote, I feel I am able to do this in an unbiased and neutral way. Additionally, I will try to find common patterns for the results.

The author of this book doesn't pretend to be a judge about whose myopia theory is right and whose theory is wrong – in the framework of their experimental conditions all of them can considered to be right in a way! Therefore, my personal views are generally clearly marked as "***Notes***".

The typical reader for whom this book was written is somebody who has myopia, or whose relative has myopia, and who is willing to take the tough route through a lot of scientific results. Maybe even some professionals in the area of myopia can benefit by getting a guide to numerous research results.

Some readers might be bored or frightened by these numerous scientific results given in this book. I decided, however, to include them to make all the recommendations and conclusions credible. There are already numerous books on the market that focus on mere recommendations without going into the details of the scientific background – I did not want to add another one to this category.

The purpose of this book is

(1) to increase the overall knowledge about myopia, particularly progressive myopia in an easy-to-read but scientifically correct format without skipping opinions and results which are still controversial

(2) to suggest the best ways to handle myopia.

The advice given in this book does not replace the treatment by a health professional, but it should enable the reader to enter detailed discussions with her/his personal optometrist, ophthalmologist or physician.

Do not expect simple "cook book" approaches to make your myopia disappear. The reader can expect to gain a better understanding of the various mechanisms and factors that produce myopia and to learn some of the means to treat its symptoms.

Do not expect to find an easy answer about the exact cause of your specific myopia. Obviously, myopia can be caused by a lot of different off-balanced processes in the human system. You will find, however, a lot of material that will enable you to consider which of your personal conditions might be part of the problem.

You will find that there are many controversies among the experts. Also, many of the cited references indicate the need for more research.

Additionally, most of the published results were collected data, which were found to be associated with myopia, and they are not definite proofs about what causes myopia. For most of these causes, however, there are potential scientific explanations given for the risk of misinterpreting associated facts as

causes is as follows[3]: It can be said, e.g. that most of the children who run across the street and get hit by an automobile were wearing tennis shoes, so therefore, tennis shoes must have caused the accidents. Obviously, the tennis shoes were only a common association, not a related factor. This is the problem in sorting out causes from associations in the study of myopia.

Nevertheless, Research has already collected a tremendous amount of information, which can be very helpful to preserve your eyesight! It does not make sense simply to wait until research has solved the myopia problem – maybe this will be too late for you.

Sections 1 to 3 detail the basic material about myopia, the remaining sections contain material which can help to create a link between the sometimes contradictory publications about myopia, and some background information which might be of interest for involved people.

Myopia is a result of more than what happens within the optical system. It is also affected by nutrition and other aspects of lifestyle. As Eaton et al. stated[4]:

"These diseases are the results of interaction between genetically controlled biochemical processes and a myriad of biocultural influences – lifestyle factors – that include nutrition, exercise, and exposure to noxious substances."

Additionally, the tremendous mental stress, which accompanies higher education and highly demanding jobs, plays a very significant role in the onset and progression of myopia (see section 3.19.1). Consequently, relaxation from this stress is very important but often underestimated (see section 3.2.2.1). By the way, near work should always be accompanied by some stress of concentration.

The author welcomes every kind of feedback – please send an email to

klausschmid@onlinehome.de

1 What is Myopia?

1.1 How does it Feel being Myopic?

Most of the readers of this book don't have to read this, because they know how it feels being myopic. They are hoping to gain some improvement, or even to cure the condition.

Other people, however, are reading this book to get help for their child or a friend. They don't have personal experience with myopia.

Being myopic means you cannot focus on distant objects without an optical device like glasses or contact lenses. Without these devices distant objects are blur – the higher the myopia the more blurry they are. Simulations of the effects of various eye problems on the vision are shown in the Internet[5].

Some people might consider glasses or contact lenses to be at the most a minor inconvenience. Children, however, often feel really handicapped, and people doing sports can feel the same. In any case, if there is a higher grade of myopia the loss of the optical device leaves the person feeling helpless.

As long as there is complete vision achieved with optical devices there might be a substantial psychological problem, but not a real medical problem. People with higher grades of myopia, however, are threatened by a permanent degradation of their vision or even blindness (see section 1.7).

At the least, then, myopia is inconvenient, and can be risky. This should be enough reason to find out about ways to minimize it. Like for every problem in life prevention is the best remedy – in spite of the fact that most often people will take action only when the damage is already happening. There is a German proverb saying "damage makes you wise" – but better get wise without too much damage. Therefore, please read the complete book.

1.2 Basic Terminology of the Anatomy of the Eye

For clarification of the terminology, a cross section of the eye is shown in Figure 1.

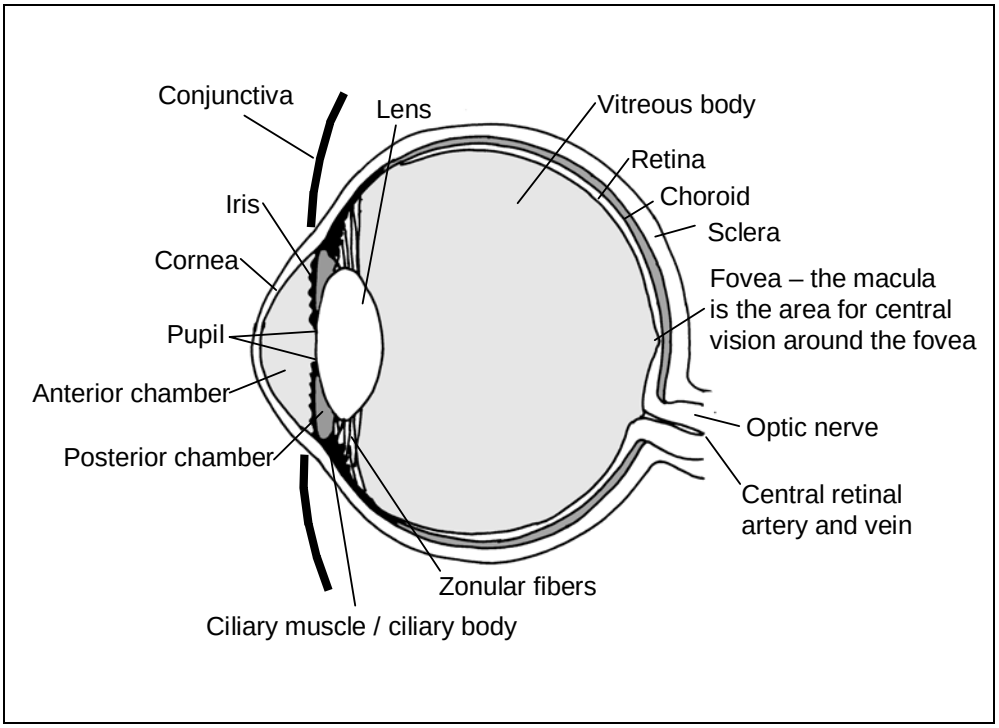


Figure 1 The anatomy of the eye

1.3 Accommodation

Accommodation is the adjustment of the refractive power of the lens of the eye to achieve an exact image of the object on the retina.

1.3.1 Myopia and Emmetropia

Myopia (or shortsightedness, or nearsightedness) is a condition in which distant objects are not displayed sharply on the retina by the optical system of the eye, because the rays converge already before they hit the retina.

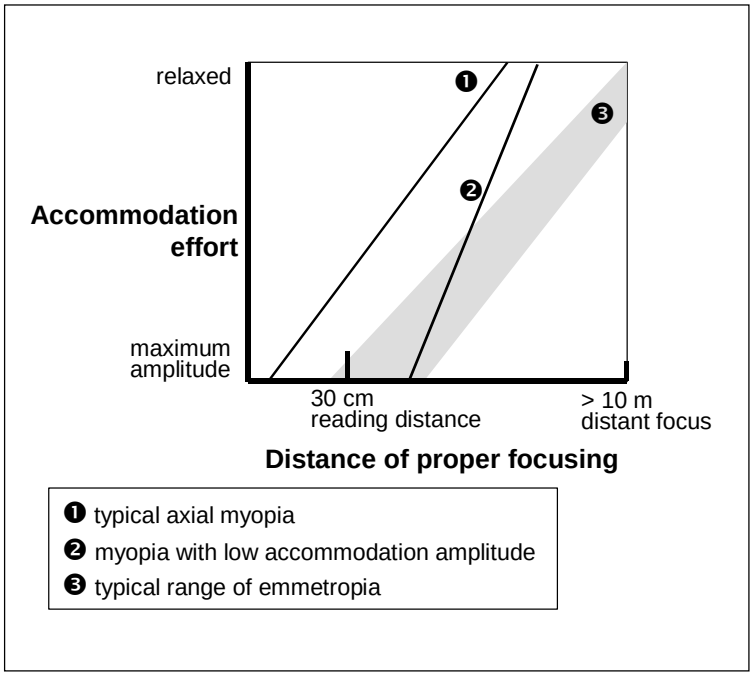


Figure 2
The accommodation effort of myopes and non-myopes

Figure 2 shows effective accommodation, when a proper focusing on the retina is achieved. E.g., in typical axial myopia even with relaxed accommodation proper focus of distant objects cannot be achieved. The emmetropic eye can adjust for all distances by an appropriate accommodation effort. Low accommodation amplitude results in an exact vision of a narrow range of distances only.

The states of myopia and emmetropia are defined according to the handling of parallel rays of light (i.e. far distance):

Emmetropia is most often defined as a state, where parallel rays of light can be focused properly on the retina. For **myopia** this focus point lies in front of the retina.

Obviously, **emmetropia** can be achieved not by one specific ocular model, but by **a range of ocular configurations**, which may all lead to a good vision at distant objects.

Emmetropia and hyperopia (farsightedness) blur into each other:

Proper distant focus can be achieved without accommodation as well as with some residual accommodation.

Near focus (e.g. for reading) is largely dependent on the person's ability to accommodate (i.e. the individual amplitude of accommodation), which decreases with age (see section 1.8).

The reasons for myopia can be (see Figure 3):

The refractive power of the lens system is too high: **refractive myopia**. Parameters of the lens system are the curvature of the cornea, the curvature of the lens at the front as well at the back, and the refractive indices of the anterior chamber, the lens and the vitreous body

The distance between the lens system and the retina is too large: **axial myopia.**

The critical reason is the second one, as it can lead to the dangerous progressive myopia by excessive stretching of the sclera.

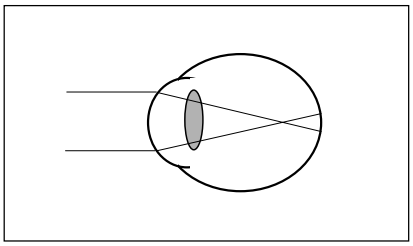


Figure 3 The focusing of the myopic eye

In the next sections the basics of accommodation, i.e. the adjustment of the eye to different distances of the objects, and some specific sub-categories of myopia will be discussed.

Literature-references to ophthalmology in general and to literature about myopia are given at the end of this book in chapter 5[6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17].

1.3.2 Theory of Accommodation

1.3.2.1 The Helmholtz Model

The general view of ophthalmic science, based on **Helmholtz**, is:

Due to its own original shape the lens would get into the shape of a round ball without a force on it. This shape corresponds to near focus.

The pulling action of the zonular fibers, which connect the lens with the ring-shaped ciliary muscle, can flatten the lens. This shape corresponds to focus on a distant object.

Consequence:

If the **ciliary muscle is relaxed**, there is a pulling tension on the lens via the zonular fibers, and therefore the focus is set to "**distant object**".

If the **ciliary muscle is contracted**, the diameter of this ring-shaped muscle is decreased, and there is no more pulling action on the lens via the zonular fibers and therefore the focus is set to "**near object**".

1.3.2.2 The Schachar Model

A modified, and in a way **very much contrary theory**, the **Schachar theory is described as follows:**[18,] "The Schachar theory suggests that the ciliary muscle contracts during accommodation, placing more tension on the equatorial zonules while relaxing the anterior and posterior zonules. (In the Helmholtz

theory, all the zonules relax). This causes an increase in the equatorial diameter of the lens, decreasing the peripheral volume while increasing the central volume. As the central volume increases, so does the power of the lens." [19, 20, 21]. This means, as Burd stated[22], "**that increasing the zonular tension increases rather than decreases the power of the lens**."

Both theories agree, however, that it is the ciliary muscle, which controls accommodation - in contrast to the theories described in section 1.3.2.4.

The idea that accommodation is a more complex function than the Helmholtz model suggests is supported by the results of Gao L et al.: "The ocular **accommodation has a great influence on refractive components** in children. **It is not only the process by which the refractive power of the lens is increased.** Furthermore, the lens itself moved forward relatively... AD [anterior chamber depth] increased while both LT [lens thickness] and VL [vitreous chamber depth] decreased significantly after cycloplegia regardless of their refractive state. However, AL increased for hyperopic eyes and decreased for myopic eyes after cycloplegia."[23]

An overall comparison between the Helmholtz theory and the Schachar theory concludes that the observations are more in favor of the Schachar theory.[24]

Additional information about the impact of accommodation on the ocular shape can be found in section 3.7.6.

1.3.2.3 The Two-Phase-Model

Mütze described the accommodation process a two-stage process with a rough focusing and a fine adjustment[25], where the phase of fine adjustment can cause an accommodation spasm.

Note:
This reminds of the saccades mentioned in section 3.6.

1.3.2.4 Two other, Controversial Hypotheses

Based on experiments, which he conducted on his own eyes, McCollim published the following very different model[26, 27]:

> "Compression of the globe by the **extraocular muscles** [which move the axes of the eyeballs] can cause the lens to accommodate" ... "accommodation can be actuated **without the intervention of the ciliary muscle**".
>
> "... a single factor, external pressure on the globe, produces two separate effects, in opposite directions: anteriorly it **accommodates the lens [by forcing the vitreous against the lens]**, and posteriorly it **elongates the globe**."

The fact that it was found by measurements that the eye is elongating during near accommodation[28, 29] supports aspects of this thesis.

Because of these experimental results, it was concluded by McCollim[26] that "with repeated periods of prolonged accommodation the lens would never have sufficient time to return completely to the unaccommodated state", and[30] "It is proposed here that the contribution of the lens in myopia is as much as or more so than the contribution of axial length" i.e. there is a substantial **time lag for the reshaping of the lens**.

Conclusion: While the reshaping is taking place the refraction will diagnose myopia. After the reshaping the refraction will not find myopia.

Note:
This time lag for the reshaping of the lens was generally found in myopic eyes (see section 3.2.1). The model of a longer lasting time lag of the shape change of the lens could explain a progression of myopia: The fitted glasses would become inadequate, and could induce a further increase of myopia (see section 3.2.1.3). In fact, the progression would depend on how long the eye takes to return to shape. This effect of a time lag for readjustment is called ***hysteresis****.*

Scanlan published another, very unconventional theory. He stated[31]: **"...the respiratory system applies air pressure to the rear of the eyeballs influencing the shape of the eyeball and hence influences how clearly we see at different distances (refractive state)."** and concludes "...myopia arises due to a reduced level of air pressure against the rear of the eyeball, causing a refractive error." According to Scanlan, **accommodation and near work "...requires that pressure in the respiratory system pressing on the back of the eyeball be reduced compared to the pressure necessary for distance work."**

Note: *The fact that myopia appears to have a close relation to stress (see section 3.19.1) gives some support to this theory. It appears doubtful whether effects off the respiratory system are solely responsible for the onset and progression of myopia, but there might be a contribution of it.*

1.4 Refractive Myopia

Refractive myopia is caused by specific deviations of the optical properties of the elements of the lens system of the eye, e.g. an anomalous curvature of the cornea or a specific refractive index of the lens, but not an axial increase in the length of the eye.

Besides mere static geometrical anomalies of the lens system of the eye, there are two rather dynamic refractive effects:

1.4.1 Tonic Accommodation and Night Myopia

Night myopia is when the eye adjusts in the dark or already in dim light, or due to a lack of image contrast **to near focus, even if all the objects are far off**. It is also called **dark focus of accommodation**, or **tonic accommodation, or resting state of accommodation**[17]**.** Consequently, a measurement of the refraction (i.e. the determination of appropriate optical glasses to obtain good vision on these distant objects) gives the result that the eye is myopic.

Night myopia can reach values of up to about - 4.0 D[32], more typical around – 1.0 D (D stands for diopters, the measure for the degree of myopia; people with myopia of - 1.0 D can see still clearly at a distance of 1 m, at – 4.0 D the distance is 0.25 m. For more details about the definition of diopters see section 1.11). At presentations where projectors with poor brightness are used, this effect might be important as well. Some authors recommend some additional optical correction for night use only, e.g. for night driving[6].

The reason for this myopia is some basic residual accommodation[33], as stated by Leibowitz et al.[34]: "the focus of the eye tends to return passively to an individually characteristic intermediate resting position or dark-focus whenever the stimulus to accommodation is degraded or when the quality of the image is independent of focus."

Night myopia decreases with age[35] and therefore it can be of special importance for young drivers at night. In one experiment with people aged 16 to 25 years, 38% had night myopia of - 0.75 D or more, and 4% had – 2.50 D or more[36].

As mentioned above, the reduced distance vision at low light is caused mainly by residual accommodation, but some other effects have an impact as well:

- The optical effect of the larger pupil decreases the depth of focus – like a large aperture of a camera
- At low light levels there is a change of the biochemistry of imaging on the retina: in bright light the receptors in the retina are cones with higher image acuity, and imaging of colors, whereas in low light the receptors in the retina are rods with reduced image acuity, and imaging of black and white only. The transition between both states, i.e. to get maximum sensitivity when moving from the bright to the dark, doesn't happen immediately, but takes some minutes[37]. This is a problem e.g. when driving a car in sunlight and entering a tunnel.
- The low light imaging by rods in the retina can be further reduced by a lack of vitamin A and zinc.

There is conflicting evidence regarding a connection between tonic accommodation and myopia. Some studies associate higher tonic accommodation with myopia, while others indicate that lower tonic accommodation is associated with myopia[17].

More recently, Tarutta et al. reported[38]: "The high values of accomodation tonus (both HAT [habitual accomodation tonus, difference between primary and cycloplegic refraction] and ART [accomodation rest tonus]) were associated with higher rates of myopia progressing."

In another paper Tarutta et al. reported[39]: "Vegetal Tonus corresponds to the accommodative rest and is determined by vegetal innervation balance of ciliary muscle. … In eyes with moderate and high hyperopia the portion of negative vegetal accommodative tonus rises."

After vacations (summer or winter), the dark focus was found to be lower and the progression of myopia to be suspended[40].

Note:
This reduction of myopia progression when the dark focus is lower can be interpreted as a "proof" that myopia is at least substantially caused by accommodative stress.

1.4.2 Pseudomyopia

If there is a **transient spasm or excessive stress** in the ciliary muscle during excessive near work, the zonular fibers are relaxed (and the ciliary muscle is not relaxed) even at distant-focus, giving the impression of a myopic eye. Especially when there is a complaint of migraine pseudomyopia should be taken into consideration[41].

It is said that this pseudomyopia frequently precedes axial myopia, and that it is most frequently found with young people[6], or that this spasm of accommodation is often wrongly diagnosed as myopia, and the prescribed minus glasses are afterwards the reason for the development of real axial myopia[41].

Another mechanism for pseudomyopia has been postulated: It was stated[7] that as an automatic reaction to mental stress the axes of the two eyes are set parallel and the focus is set to "distant", and the pupils are opened wide. In a hunter-gatherer lifestyle, this has a survival advantage in that it may lead to the early detection of danger. However, if a child working at near focus - like during a test - will subject the eyes to competing forces:

Between near focus and distant focus (ciliary muscle), and

Between inward adjustment of the axes of the eyes (convergence for near work) and parallel adjustment.

This can lead to a spasm of the involved muscles and further to pseudomyopia (and maybe to permanent myopia).

Besides these effects of the ciliary muscle, transient myopia, which is caused by a hysteresis (i.e. a longer time necessary for readjustment) of accommodation, can be based on:

A transient ocular elongation caused by accommodation (see section 3.7.6).

A hysteresis of the shape of the lens as well (see sections 1.3.2.4 and 3.7.4).

1.4.3 Other Types of Myopia

There are some other types of myopia:

Keratoconus is when the shape of the cornea is not uniform but more pointed; this can add additional refractive power of up to –20 D.

In some unusual cases, an **extraordinary refractive power of the cornea and / or the lens** may result in myopia with a normal length of the eye.[42]

With increasing age the **refractive index of the cornea** can be changed, to result in very moderate myopia.

Beyond 40 to 50 years **presbyopia** appears, i.e. the **lens loses some (and later all) of its flexibility** due to structural changes. Fewer authors attribute presbyopia to a **weakening of the ciliary muscle** by age[43]. Generally, this results in problems with near work and accommodation. If, however, the lens shape is "frozen" in a slightly accommodated state, problems with distant focusing may appear, which corresponds to myopia.

Diabetes can change the refractive index of the lens, leading to myopia if the blood sugar is elevated, and to hyperopia (farsightedness) if the blood sugar is low[44] (see section 3.24.1).

Antibiotics like sulfonamides, tetracyclines and corticosteroids can induce myopia[45].

Amblyopia is when the visual acuity is reduced without visible pathologic defects. In most cases one eye only is affected. The affected eye is often **highly myopic.** This is named anisometropic amblyopia (see section 3.30.8).

1.5 Axial Myopia

Axial myopia occurs if the length of the eyeball is more than the average length of about 24 mm[46]. In this case the ratio of the length of the eye (anteroposterior dimension) to the height/width of the eye (transverse dimension) is larger than 1.0. Roughly 1 mm in length corresponds to - 3.0 D.

The increase in the length of the eye is said to happen only at daytime[47].

There are several forms of axial myopia:

Simple myopia (sometimes called **school myopia**), which normally starts at age 10 – 12, stays normally under - 6 D and remains quite stable after the age of 20 years. No structural defects of the eye can be diagnosed in this case.

Benign progressive myopia up to 12 D, which is often stabilized at an age of 30 years. Most likely structural / biochemical defects of the eye can be diagnosed.

Malign myopia, which does not stop progressing at all. Up to – 30 D can be reached, with serious consequences, which may lead to blindness. Structural / biochemical defects of the eye can be diagnosed.

Pathological myopia, if there are already pathological changes in the eye (see section 1.7), independent from the refractive error.

1.6 "What Type of Myopia Do I Have?"

The main and most worrying question is, whether it is a simple (not dangerous) myopia, or a myopia that can lead to a permanent damage of the vision (see section 1.7). This question can be answered only be an optometrist or an ophthalmologist, who will check the background of the eye for some signs of already appearing damage.

It was stated that only 1 in 1000 people have true myopia[48].

1.7 Consequences and Risks of Higher Myopia

Some numbers from the statistics about the consequences of higher myopia[6]:

England, 1966: Myopia was responsible for 8.8% of blind registrations.

England, 1972, age between 50 and 59: Myopia was responsible for 18.2% of blind registrations, only behind diabetic retinopathy.

Bavaria/Germany, 1992, up to age 18: Myopia was responsible for 11.5% of blind registrations[49].

Myopic macular degeneration is the seventh greatest cause of registered blindness in adults in Europe and in the United States, but has become the leading cause of blindness in Taiwan[50].

Myopia accounted for 5% of the causes for blindness of people aged 20 to 59 years in Denmark[51].

2% of Americans have pathologic myopia52.

For refractions over – 9.00 D 52.4 % of the myopes in Australia show retinopathies, for over – 10.00 D 89.6 % of the myopes in China show retinopathies[53].

As the rate of myopic people is still increasing significantly today, the problem of resulting blindness can also be expected to rise further.

By the way: My motivation in writing this book is to inform people of this risk, so they might be able to reduce it by preventative measures.

It is not the intention to frighten you with these data, but to trigger you to do your very best to avoid these potential consequences of higher grades of myopia.
Most of the readers of this book will never be affected by the potential risks of myopia, but I am very glad if some of the readers can avoid or reduce permanent eye damage by following advice given in this book.

A basic effect of high myopia is that the posterior sclera shows substantial thinning by the elongation of the eye. The normal sclera has a thickness of about 1.35 mm on the back of the eye. A highly myopic eye has a typically reduced thickness of the sclera of about 0.2 to 0.5 mm [7] and a thinned choroid as well. It is, however, still an open question, whether the thinning of the sclera is due to:

An **optically** regulated mechanism,

An excessive **mechanical** stretching force,

A **defective connective tissue** of the sclera.

Section 3 contains more information about these issues.

Basic reasons of most of the serious consequences of myopia are vitreochorioretinal dystrophies, i.e. **disturbed structures** of the layers of vitreous, choroid, and retina. It was found that 52.6% of people with weak myopia and 86.4% of people with high myopia had this disorder[54].

Some basic pathological consequences of high myopia can be[6, 55]:

Retinal detachment:

There is an elevated risk for retinal detachment, i.e. the retina is separated from the choroid and the sclera, often accompanied with tearing of the retina. Retinal lattice degeneration and retinal breaks are often early signs of later retinal detachment[56]. Some publications, however, are contradictory with respect to an increasing risk with the degree of myopia. Some people are saying that there is an increased risk for myopes, which is, however, not dependant on the degree of myopia[9]. Other sources state a risk for retinal detachment e.g. for 0 D to – 4.75 D a risk of 1/6662, for – 5.00 D to – 9.75 D a risk of 1/1335, and for more than – 10.00 D a risk of 1/148[6]. In other words, an additional risk factor of 3 for low myopia, and up to 300 for high myopia[57] was reported.

Besides the stress on the retina by a permanent elongation of the myopic eye, **excessive stress by accommodation can be responsible for retinal detachment**, as Arruga stated[58]: "One physiological condition of importance in retinal detachment is the movement of the anterior part of the retina in accommodation."

See also section 3.7.6 about the elongation of the eye during accommodation.

Vitreous liquefaction and detachment:

The vitreous body between lens and retina consists of 98% water and 2% fibers of collagen. It gradually becomes liquefied with age, and especially in myopic eyes [56, 59]. This is due to a loss in the regular arrangement of the fibers. In early stages, small objects can be seen when looking at bright and uniform backgrounds (called fleeting flies, or floaters): "Most of the time they are nothing to worry about, but sometimes they can be a symptom of a retinal tear[60].". In later stages, the vitreous body can collapse and lose its connection to the retina. This separation is connected with the risk of retinal detachment and corresponding damage of the retina. Immediate medical examination is necessary if symptoms like flashing lights or a rain of soot can be seen. No treatment is available for vitreous detachment by itself. About 6% of "normal" people between age 54 to 65 and 65% of the people between age 65 to 85 have a vitreous detachment. The higher rate of vitreous detachment of myopic people is sometimes explained by the larger volume, which has to be filled by the vitreous body.

It was concluded that the liquefaction is caused by the functional disorder of the blood-retinal barrier in myopia[61.]

Various Myopic maculopathies:

Myopic macular degeneration (MMD) / Choroidal neovascularization (CNV) / is also a consequence of "normal" macular degeneration, and it is caused by **abnormal blood vessels that grow** under the center of the retina. It generally occurs among people over 30 and can result in

a progressive loss of vision. The worldwide incidence of CNV due to pathologic myopia is estimated to be 50,000 new cases per year excluding Asia, where the rate may be even greater due to a higher prevalence of pathologic myopia[62] (see section 3.25 about a treatment for CNV).

Myopic macular degeneration is said to be the seventh greatest cause of blindness of adults in Europe and the USA, and has become the leading cause of blindness in Taiwan[50], and the most common pathological consequence of myopia. Prevalence of MMD for high myopia was reported to be between about 10% and 60% in the various studies[63].

There can be a thinning of the choroid and the retina and a **loss of capillary vessels** in eyes with high myopia[2] and as a consequence an atrophic **loss of retinal cells** (i.e. cells are dying), resulting in a loss of vision in this area[13] (visual field defect).

In pathological myopia the **death of retina cells (apoptosis)** can occur due to various biochemical processes, e.g. related to oxidative events (see section 3.18).

Furthermore, there can be **bleedings** in the retina and the choroid, leading to a partial loss of vision[13].

Posterior Staphyloma:

In pathologic myopia there can be a herniation-like deformation ("out-pouching") of a thinned sclera, which can hardly be corrected with lenses. It also leads to other complications.

Glaucoma:

The increased pressure within the eye that often accompanies myopia (see section 3.7.2), can damage the optic nerve. The results of older techniques for measuring the intraocular pressure of myopes were wrong: even when the pressure was high, the softer myopic tissue was interfering with the measuring process in a way that the result was a normal, i.e. lower pressure than in reality. Later a measurement called "applanation tonometry" was invented. This technique is claimed to be independent from the rigidity of the sclera. It is said that **open-angle glaucoma** occurs twice as often with the myopic eye as with the normal eye[6].

Cataract:

The lens is loses its transparency. It is reported that myopia induces an earlier onset of cataracts. Statistical data are lacking[57].

Chui TY et al. reported[64]: "… data indicated that approximately 15 D of refractive error doubles the spacing between retinal neurons, thereby **halving peripheral resolution acuity** relative to the emmetropic eye."

Soft contact lenses, and the complications of refractive surgery, can lead to infections, which may cause blindness[57].

Each myopic person is strongly advised to see an ophthalmologist at the slightest sign of visual abnormities, and people with high grade of myopia should have the background of their eyes checked regularly!

On the other hand, even if there is a high degree of myopia at a young age already, there is still hope, as Goldschmidt and Fledelius found[65] after the observation of the development of the myopia of 14 year olds with at least – 6 D over 40 years "...the adult visual prognosis for working age appeared better than usually claimed. There seems to be a correlation between degree of myopia at age 14 and consecutive visual loss, but it was not possible to identify subjects at high risk at that early age."

Notes:

In many cases, a general systemic problem may cause one of these diseases, and also myopia. This then explains the noted association, without implying that myopia is the cause of the disease. In these cases the therapy should focus more on the systemic problem, and not primarily on the optical myopia problem only (which should be positively influenced by the therapy as well).

As progressive, pathological myopia is based on defects of the connective tissue, the connective tissue related coronary problem mitral valve prolapse (MVP) might have an increased probability, which makes preemptive measures still more appropriate, as stated by Yeo et al.[66]: "Although most patients with MVP are asymptomatic or have minor symptoms, it is associated with significant morbidity."

Statistics from France, reported by Leveziel et al.[67]:

"Myopia severity was defined as mild (-0.5 to -3 D), moderate (-3 to -6 D), high (-6 to -10 D) and very high (more than -10 D).

The prevalence of mild, moderate, high and very high myopia was, respectively, 65.95%, 26.14%, 6.72% and 1.19%. The prevalence of macular complications in the high and **very high myopia groups** was 0.5% [0.39-0.64] and **4.27% [3.49-5.17]**. The prevalence of blindness or vision impairment was observed in 10.10% [8.91-11.39%] of the very high myopic group.

At 60 years old or over, the prevalences of blindness or vision impairment were, respectively, 9.75% [7.91-11.85%] and **25.71% [21.00-30.87%]** in the high and **very high myopia groups**."

1.8 Myopia and Age

Myopia may be categorized according to the age of onset:[6]

Congenital myopia exists already at birth and stays through the whole life. 1-2% of the population is in this category.

Youth-onset myopia starts between ages 5 and 20. In the USA about 20% of the population is affected by this category.

Early adult-onset myopia starts between ages 20 and 40. About 8% of the population is affected by this category.

Late adult-onset myopia starts after age 40.

In general, the earlier the myopia appears, the higher are the D values it will reach[6]. But on the other hand, as stated by Goldschmidt[68] "myopia progression can stop at any time transiently or permanently". This statement, based on experience of optometrists and ophthalmologists, shows how shaky the overall knowledge of myopia development still is.

Independent of myopia, it was found that "There was a **significant correlation of scleral stiffness with age** …"[69], which gives some hope to myopic people, because the increasing rigidity results in less axial growth or even in a standstill of growth.

Du et al. reported[70] "… cohort study found **continuing axial elongation in adults with high myopia.** The risk factors for elongation do not appear to be modifiable, so **prevention of myopia** may be the best approach to reduce the incidence of pathologic myopia and its complications in the future."

Note:
This effect can be explained as well by a generally weak connective tissue of the sclera as well as by the shape of the sclera of myopes (see section 3.3.11)

1.9 Accommodation and Age / Presbyopia

The average power of accommodation, of which the eye is capable, depends on age:

10 years:	about 12 D, i.e. an emmetropic person can see clearly from infinity to 0.08 meter
30 years:	about 8 D, i.e. an emmetropic person can see clearly from infinity to 0.13 meter
50 years:	about 2.5 D, i.e. an emmetropic person can see clearly from infinity to 0.4 meter
60 years:	about 0.6 D, i.e. an emmetropic person can see clearly from infinity to 1.7 meter

D stands for diopters. This dimension equals to the reciprocal value of the focal distance of a lens (see section 1.11).

This process of a diminishing of accommodation is called **presbyopia**.

Shovlin summarized[43]: "Today, two schools of thought predominate about what causes presbyopia. One, that presbyopia results from a hardening of the lens and stiffening of the lens capsule with age so that the lens cannot change shape. And two, that the ciliary muscle, as it ages, loses its ability to contract and change its configuration. However, both are happening simultaneously."

Additionally, there are numerous other changes of the aging eye.[71]

In general, people are becoming more hyperopic (i.e. farsighted) with old age, which appears to correlate more with the Schachar theory of accommodation than with the more widely accepted Helmholtz theory of accommodation[24] (see section 1.3.2).

Consequently, almost everybody has to wear glasses or contact lenses during a more or less extended period in life. An older person with moderate myopia can often read by simply taking the glasses off. And for wearers of contact lenses there is the chance to wear bifocal contact lenses. This is a reason to avoid corrective surgery.

The graphical presentation of this mechanism is shown in Figure 4.

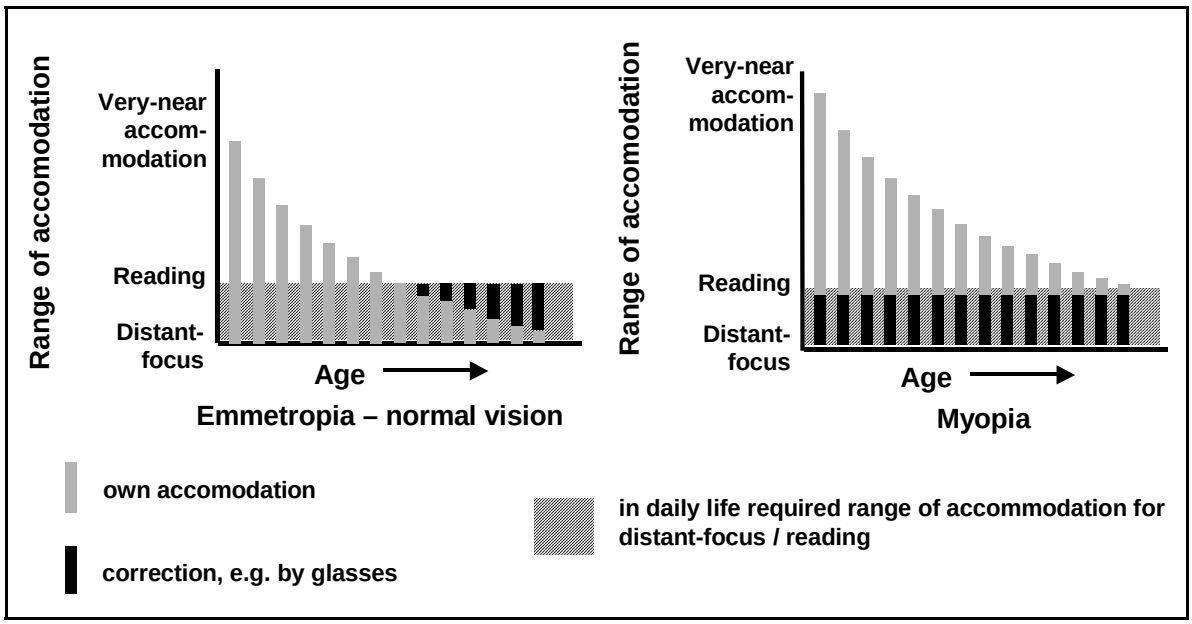


Figure 4 The change of the accommodation amplitude with age

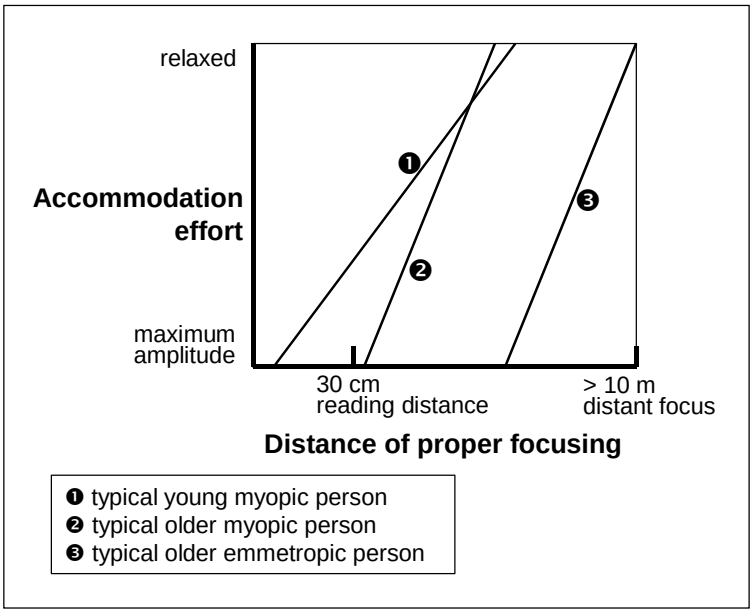


Figure 5 The accommodation effort with respect to age and distance

Figure 5 is a somehow different representation of the relation between the accommodation effort and the distance for which proper focusing can be achieved with increasing age. Even emmetropic persons need glasses to cover the range from reading distance to distant focus. Their glasses have to take care of the reading distance, the myopes's have to take care of the long distance.

It has been claimed that only very few non-myopic people over 60 are still able to accommodate, and it was concluded from research that a hotter climate accelerated the decrease in accommodative power[16].

On the other hand, many people report that **with older age their myopia decreases** because of the mentioned aging process of the lens and the ciliary muscle.

Note:
Quite frequently older people report that their myopia is decreasing, attributing this to presbyopia. The reason, however, might be as well a ***beginning of diabetes****, which changes the refractive power of the lens (see section 3.24.1).*

1.10 Age Related Geometrical Changes of the Eye

The refractive power of the cornea shrinks from 47 to 48 D in infants to 43 to 44 D by the age of 3 to 9 months and remains afterwards rather stable[534].

The crystalline lens experiences by far more laterations. The lens power shrinks from 41 D in infancy to 22 to 23 D at the age of 14 years[534].

It was concluded by Garner et al.[72], "that the balance between the decrease in crystalline lens power and the increase in vitreous length is the major factor in maintaining the tendency to emmetropia in these children."

A disturbance in the described reduction of the lens power might already contribute to the appearing of myopia:

Mutti D et al. reported[525]: "Before myopia onset, the crystalline lens thinned, flattened, and lost power at similar rates for emmetropes and children who became myopic. **The crystalline lens stopped thinning, flattening, and losing power within ±1 year of onset in children who became myopic compared with emmetropes** statistically adjusted to match the longer VCDs [vitreous chamber depth] of children who became myopic."

In general, it is said that about 80 percent of young children are hyperopic, and this hyperopia can increase until to an age of 7 to 8 years and decrease thereafter until to an age of about 19 to 20 years[217].

1.11 The Refraction

1.11.1 Basic Procedure

To determine if myopia exists, people have to see an optometrist or an ophthalmologist. It is generally recommended, especially for children,[7, 12] that any remaining accommodation (i.e. stress of the ciliary muscle) is eliminated as much as possible before doing the test. **Cycloplegic agents** can achieve this, i.e. by the application of eye drops, which relax the ciliary muscle. The residual accommodation of the ciliary muscle, which exists if no cycloplegic agent is applied results in **overcorrection of myopia**[73]. If this relaxing of the ciliary muscle is not done, pseudomyopia may still exist. In reality, however, hardly any practitioner appears to use these cycloplegic agents – maybe because it takes too much time until the agents work (about 30 minutes).

A comparison between non-cycloplegic and cycloplegic autorefraction showed that **non-cycloplegic measurements generally result in too high minus diopters**[74]. Zhao et al. reported[73]: "**Noncycloplegic autorefraction was found to be highly inaccurate in school-age children** and, thus, not suitable for studies of refractive error or for prescription of glasses in this population."

In detail, they found that the error is largest for hyperopes and smaller for myopes, but still -0.41(+/-0.46D) for myopia of -2.00 D or more. An error, which was still larger – 0.84 D, was reported by Fotedar, who concluded[75]: "Precycloplegic autorefraction substantially overestimated the proportion of children with myopia".

Li T et al. reported[76] "The proportion of myopia decreased from 78.1 per cent before cycloplegia to 71.4 per cent after cycloplegia, while the proportion of hyperopia increased from 12.1 per cent before cycloplegia to 21.4 per cent after cycloplegia." This means that **an accommodation spasm resulted in an unjustified high minus evaluation**. Additionally they found that **this error was disappearing after an age of 12 year of the examined children**.

Gu et al. reported based on experiments with children of mean age 9.7 years[77]: "Non-cycloplegic refractive error **overestimates myopia by approximately one diopter**."

It was stated that more than 90%(!) of children under an age of ten years are hyperopic, i.e. their eye is (still) too short[78].

If these children are not wearing plus glasses, they have to accommodate even when focusing at far. Consequences:

The inadequate high accommodation will result in an adjustment of the axes the eyes that can be **mistakenly diagnosed as phoria** (see section 3.5.1), and as the images of both eyes do not match properly, the image of one eye might be suppressed by the brain. This can result in a permanent damage of the eye, which "was switched off".

The permanent and excessive accommodation (especially at near work) can easily result in a **spasm of the ciliary muscle** and corresponding negative effects.

A flawed refraction can very likely be the entry to myopia.

Therefore, strong effort should be made to have the refraction of children tested by an ophthalmologist, who has a very good professional background and who is taking the problem of myopia of children very seriously.

A **comparison between autorefraction and "normal" prescription** showed a tendency of overcorrection by autorefraction[79].

Therefore, by not using these drops, often more glasses can be sold, and herewith a cycle of a permanent increase in myopia can be initiated, if no cycloplegic agent is used.

Notes:

- *Open question: Which effect (autorefraction versa lack of cycloplegia) is contributing what share in the overcorrection?*
- *According to other results and corresponding theories there is also a substantial accommodation hysteresis besides the one caused by the ciliary muscle and other ocular muscles, i.e. a hys-*

*teresis (i.e. a time lag for getting back to the original shape) of the ocular shape (see section 3.7.6) and even of the lens (see section 3.7.4). Cycloplegic agents **cannot eliminate all these hysteresis (pseudomyopia) effects**.*

- *The omission of cycloplegic agents can contribute to the progression of myopia because the prescribed glasses can be too strong, which causes a further progression of myopia (see section 3.2 and 3.3).*
- *According to personal experience cycloplegia is rarely done (this attitude might be very different in different countries).*
- *Another potential source of errors is a chart for reading, which is badly illuminated: In this case, hidden **night myopia** may lead to an over-correction (see section 1.4.1).*
- *Psychological stress can have an immediate impact on refraction (section 3.19). Stress could occur in school, or during an eye examination. If glasses are prescribed as a result, they in turn can initiate myopia that didn't previously exist. The Bates method (section 3.2.2.1) focuses on this issue.*
- *As it is shown in the following sections, this **over-correction can induce a further increase** of "real" axial myopia.*
- *The fitting of glasses should **not be based on autorefraction only**; it should be double-checked by a conventional refraction.*

In 95% of the cases, the results of the refraction can be reproduced within 0.5 D - assuming there is no effect of pseudomyopia or hysteresis of accommodation at all. These hysteresis effects can make refraction difficult, and can finally contribute to a permanent **"lens-induced" progression** of myopia (see section 3.3).

In different countries and by different authors different units are used to describe the amount of myopia and loss of visual acuity:

Diopter, abbreviated **D**: The refractive power of a lens (to correct the myopia) can be expressed by the reciprocal value of the focal distance: -1 D corresponds with a focal distance of 1 m. People with myopia of -1.0 D can see still clearly at a distance of 1 m (at -2.0 D the distance is 0.5 m). The refractive power of the prescribed glasses is given in D with a minus in front.

Snellen chart: This standard is more than 100 years old. 20/20 means that you can see at a distance of 20 feet what a "normal" person can see from a distance of 20 feet. 20/40 means that you can see at a distance of 20 feet what a "normal" person can see from a distance of 40 feet, and so on. Standard distance for myopia tests is 5 to 6 m. 20/40 is required in most States of the US to pass the Driver's License Test.

Decimal quotients: In some countries the basic principle of the Snellen chart is used - the quotient of the distance where the patient can read to the distance where "normal" people can read. The result is given, however, in decimal units. A vision of 1.0 corresponds therefore to the visual acuity of a "normal" person. Some people, especially kids can have better resolutions up to a vision of about 2.0. Sometimes this decimal number is given in %, i.e. a visus of 1.0 corresponds to 100%.

Visual acuity or visual efficiency: Sometimes another conversion from the Snellen chart numbers to percent is used. The table below contains the corresponding information.

Angle-resolution: The visual acuity of the "normal" person (i.e. vision 20/20 or 1.0) corresponds with an angle-resolution of rays, which are incident on the eye, of 1 minute.

Besides plain spherical myopia, often **astigmatism** is diagnosed: This is the contribution of non-spherical irregularities of the eye, which can be compensated by added cylindrical lens-components. The power of these cylindrical lenses is given in D, too (same definition as above). The prescription will give additionally the circular direction of the astigmatism in degrees. Combined spherical and cylindrical glasses are called toric.

The "best spherical fit" for toric glasses (i.e. for eyes with astigmatism) can be roughly estimated as: Spherical D + ½ · astigmatism D.

Visual acuity can be described by several parameters, of which the D figure or its equivalent is one. Other factors include astigmatism. A very rough cross-reference is shown in Table 1[80, 81]:

Diopter D	Snellen chart, 20/ ...	Decimal	Visual acuity / efficiency[82]
- 0.50	20/25 to 20/30	0.8 to 0.7	95% to 90%
- 1.00	20/30 to 20/50	0.7 to 0.4	90% to 75%
- 3.00	20/300	0.07	15%
- 4.00	20/400	0.05	10%

Table 1 Some different methods to measure visual acuity

Sometimes the numbers for the diopters D are given in a different representation without the decimal point, e.g. - 1.00 as 100, - 6.50 as 650 etc.

If you want to **keep track on your myopia by yourself you can use Snellen Charts**, which can be downloaded from the Internet and printed[82], or which can be displayed and used directly on your computer monitor[83].

Very frequent visits to an optometrist for measurement of refraction bears the risk of a subsequent overcorrection, if the optometrist is not very well informed about myopia prevention and all the recent research results.

The result of a study in the USA was that, as Donahue stated[84] "... a significant percentage of [preschool] children are probably **prescribed glasses unnecessarily**." In this study, specialized pediatric ophthalmologists were most careful in prescribing glasses.

A simple method to check any over- or undercorrection[85, 86]:

The refractive index of red and green light is different, and green light is focused about 0.5 diopters closer to the retina than red light.

Therefore, if you can see numbers or letters on a distant chart clearer and with more contrast when looking through a red glass or foil than through a green one, there is undercorrection.

If the contrast is better for the green picture, there is overcorrection.

As a result, a cold-color light results in less accommodative stress for the eye than a warm-color light.

Note:
The first unnecessary glasses might be the first step towards myopia (see section 3.2)

The regulations about who is authorized to examine the eye and to prescribe glasses or contact lenses are different for the various countries (e.g. optometrists, ophthalmologists[87] ...). Definitely, the selection of the right professional is extremely important, but it is hard to give any selection criteria. A discussion with the respective professional about some of the issues described in this book may be helpful to assess whether the professional is familiar with the current research results.

1.11.2 A Method for Refraction: Fogging

To release any spasm of accommodation it was stated that long time experience showed that the **application of strong plus glasses (or plus additions) prior to the refraction was more efficient** than cycloplegic agents were, as Viikari expressed[41]: "... when the eye is atropinized [it] hold out for many years in the spasm position".

It was claimed that a faulty refraction where a spasm of the ciliary muscle was not considered results very often in a diagnosis of myopia (with the corresponding prescription of minus glasses) where in fact there is hypermetropia (farsightedness, which requires the prescription of plus glasses. An existence of

migraine is sad to be already a strong indication of a spasm of the ciliary muscle, or a problem with accommodation in general.[41]

A means to break this spasm is called fogging[88].

This spasm of the accommodation can be attributed in many cases to a general stress-situation of a person (see section 3.19.1 about stress). Obviously, the prescription of glasses is not decreasing the stress; in many cases, it increases the stress.

Viikari summarized the fogging method as follows[41]: "Accommodation is an interesting series of psychophysical occurrances. It comprises both a positive and a negative component; in the regulation of positive accommodation there are two basic events: a partial regulation, which means the rough approaching of the object looked at and a second or fine regulation which leads to the actual focusing (Muetze 1956, p. 83[25]). By fogging one aims at voluntary, knowing prevention of the phase of adjustment, thus also preventing the exact focusing which provokes the spasm of accommodation."

The typical procedure of fogging starts with a high plus value like + 3.0 D.

1.11.3 The Range of Clarity

The aim is to predict the onset of myopia as well as hyperopia and to take measures against it.

Miele JR had described the range of clarity as follows[89]:

There is a Plus Subjective Test (PST), where the refraction is started with a plus lens where the patient can see 20/200 letters on the distant chart (similar like in the fogging technique). Then the plus power is reduced until the patient sees 20/20. The difference of the plus lenses at the beginning and at the end is the PST-number.

There is a Minus Subjective test (MST), where the refraction is started with additional –4.00 D on top of the last lens at the PST test. Then the minus power is reduced until the patient sees 20/20. Again, the difference of the minus lenses at the beginning and at the end is the MST-number.

With these numbers, PST and MST the optimal lens power can be determined[89, 90].

2 What Causes Myopia in General?

Chapter 3 will summarize the research. This chapter gives an overview of some of the main hypotheses concerning the development of myopia.

2.1 Is Myopia Inherited?

In the past, the official medical view considered myopia to be simply inherited, and in PubMed a search for myopia plus genetic results in numerous results.

No question, heredity plays a key role[91, 92] – everybody is determined by heredity and environment. In the same way, however, as there are talents of various levels, which can be compensated for to a great extent by personal energy, hard work, and methodology, all the possibilities should be tried to influence the "chemical factory" of the body by optimizing external parameters, e.g. by appropriate nutrition and adequate behavior.

Fact is,

- Myopia is **dramatically increasing** compared to the past[1, 7, 93, 94], and many children are becoming progressively myopic with **none of the parents or grandparents being myopic**, and even populations like Eskimos, where myopia was extremely rare before, are getting highly myopic.
- Myopia can be easily **created artificially** in experiments with animals[95].
- Myopia occurs in different frequencies in **different regions of a country**[96].
- Myopic parents have more often myopic children[97]: if both **parents are myopic**, the risk for the children to become myopic is sevenfold.

Two arguments about this controversy:

- Goldschmidt states[98], " Twin studies indicate a strong genetic influence and a weak environmental impact, while extreme myopia prevalences among selected population groups (university students) point to the opposite."

  Note:
  In case myopia is caused primarily by personal habits (which includes e.g. reading), a reported genetic influence might be more related to identical habits of twins than to a biochemical cause.

- Morgan states[99], "... evidence for low prevalences of myopia in Indians growing up in India, while Indians in Singapore have much higher prevalence rates."

The conclusion is that myopia itself is not inherited. Rather, biochemistry is, and it reacts differently to various environments.

Jones-Jordan et al, however, insisted genetic facors are dominating[100].

As Lyhne et al.[101], who did research with twins expressed very well:

"... results indicate a high heritability for ocular refraction and its determiners and thus suggest that environmental impact on refraction is not significant. However, the epidemiological association between educational length (near work) and myopia, the evidence on increasing myopia prevalence within a few generations, and the theory of gene-environment interaction imply that **some individuals might be genetically liable to develop myopia if exposed to certain environmental factors**".

With respect to a different medical problem the relation between genes and lifestyle was put in very clear words:

"Genes are always a factor of our health, but that is the only factor we can't do anything about. Genes only represent our predisposition & potential to encounter certain problem or disease. It is our life and our lifestyle as whole that makes the final decision on whether we are going to experience certain problem or not.[102]"

In other words, it is often not the myopia, which is inherited, but the susceptibility to specific environmental conditions like excessive near work.

Moreover, specific genetic dispositions can make vulnerable to specific environmental conditions.

Note:

The fact that some people do not develop myopia in spite of very adverse conditions is a clear indication that heredity is involved in any case, the question is just to what extent.

Morgan has a different view[103]:

"Overall, while there may be a small genetic contribution to school myopia, detectable under conditions of low environmental variation, **environmental change appears to be the major factor increasing the prevalence of myopia around the world**. There is, moreover, **little evidence to support the idea that individuals or populations differ in their susceptibility to environmental risk factors."**

Note:
Morgan refers explicitly to school myopia and not to the higher grades of myopia and progressive myopia.
The fact, however, that many individuals do not become myopic in spite of very adverse environmental conditions speaks against the strong thesis of Morgan ("...little evidence to support the idea that individuals or populations differ in their susceptibility to environmental risk factors.")

A reader of this Myopia Manual expressed another likely possibility with respect to the inheriting of myopia: "The parents probably become myopic because they live in similar conditions as their offspring."[104]

Another point of view stated by Morgan[99]: "Thus, parents with longer than average eyes would tend to have children with longer than average eyes ... however, if average eye size is increasing due to environmental effects, a high proportion of children would become myopic."

In principle almost all the facts about myopia that will be presented in the next sections are either connected with the way of living of people, or with biochemical processes. Largely, however not completely, these biochemical processes are determined by heredity.

A few authors have reported a connection of few specific chromosomes with myopia[105], but contradiction with other results followed immediately[106, 107]. One expert states: Future genetic therapies of myopia are highly unlikely, because it appears that numerous genes are having an impact on myopia[97].

On the other hand, many papers show the fact that myopia often runs "in the family"[108, 109], and that myopia is very clearly more common in some populations than in others (see section 3.1).

By the way: Influences like nutrition during pregnancy have a high congenital impact on the child's health. In addition, the "individual biochemical factory" is built very early in life and cannot be changed later. An example is the copper metabolism - which might have an impact on myopia[110, 111].

Basically any biochemical heritage can become effective via one of these two alternatives:

Via a biochemical process which cannot be modified, and whose results cannot be modified either.

Via a biochemical process which can be modified, or whose results can be modified. An example: People suffering from favism, an enzyme defect (a variant of G6PD deficiency) which leads to acute anemia after eating e.g. fava beans. Simple advice after somebody is diagnosed with this deficiency: Do not eat these beans. The literature gives further examples of "Nutritional Regulation of Gene Expression[112]".

It is my aim to offer assistance in the second case and to motivate people not to become fatalistic. Further, biochemistry is not in itself good or bad: An effect that has a disadvantage in one respect, can have an advantage in another respect (e.g. the G6PD deficiency mentioned above is said to offer protection against Malaria).

A simple analogy: If the engine of a car is prone to overheating through a design fault, the damage can be avoided in most cases by carefully watching the cooling water level, selecting top grade motor oil, and avoiding mechanical overload. Why not apply the same strategy to the human body, instead of hiding behind the word heredity?

Some facts, which can contribute to the answering of the question whether myopia is inherited can be found in section 3.1 ("Distribution of Myopia by Region, Age, Gender and Ethnicity").

As some people do not become myopic even under very adverse conditions, **it could always be claimed that myopia is caused by genetic heritage, even if it was demonstrated that without these adverse condition myopia did not occur.**

The reason for this conflict is that the three potential causes for myopia,

connective tissue disorders (see section 2.2)

active growth by imaging effects (see section 2.3)

mechanical effects (see section 2.4)

are in one way or another influenced by the genetic heritage of the individual person.

Maybe there is a rather simple distinction whether the myopia of an individual person is caused mainly by genetics only or by interworking of environment and genetics: Low W et al. reported[113] "Neither near work nor outdoor activity was associated with preschool myopia."

Finally, Verhoeven VJM et al. found[114]: "Individuals at **high genetic risk in combination with university-level education had a remarkably high risk of myopia** (**OR 51.3**; 95 % CI 18.5-142.6), while those at **high genetic risk with only primary schooling were at a much lower increased risk of myopia (OR 7.2**, 95 % CI 3.1-17.0)." [OR = Overall Risk, CI = Confidence Interval]

See also section 3.30.7.

2.2 Connective Tissue Disorders

In the case of connective tissue disorders, the structure of components of the myopic eye shows significant deficits. These structural deficits can have various origins:

Clearly inherited (like in case of the Marfan syndrome).

Appearing as a form of genetic variation, which happened after birth.

An acquired disorder, e.g. caused by interactions of the immune system, or by inappropriate nutrition, or by other environmental or behavioral circumstances.

An example for the impact of the connective tissue on the highly myopic eye by Chang et al.[115]: "... that the fiber bundles of highly myopic eye were of thinner lamellar arrangement, with looser collagen matrix distribution and decreased collagen fiber diameter."

Computer tomography measurements showed that the more severe the myopia is the more reduced is the density of the sclera[116].

Section 3.3.2 describes some results with respect to the connective tissue.

2.3 Active Growth by Imaging Effects

After birth, the eye is too short for an optically correct focus. During growth, the eye expands by some feedback mechanisms to the proper length. This process is called **emmetropization**[117]. Animal experiments have investigated this process in detail, but there are still a lot of open questions about what goes wrong when some people become myopic, or even progressive myopic, when others in the same environment don't. This active growth mechanism will be described in more detail in section 3.3.

Note:
Obviously, the growth of the eye in young age is characterized at least partly by an increase in the number of cells. The extension of the eye in myopia, sometimes described as growth as well, is characterized mainly by a change of biomechanical properties (see section 3.3).

2.4 Mechanical Effects

There is quite general agreement that myopia has some connection with accommodation. One explanations is the influence of the strain of the various muscles which are involved when doing near work – not just only the **ciliary muscle** for accommodation, but also various **extraocular muscles** which are controlling the position of the axis of the eye (see sections 1.3.2.4 and 3.7).

In this context, there is the interesting result that **the thickness of the ciliary body increases with increasing myopia and axial length**[118].

The influence of accommodation on myopia is discussed in more detail in section 1.11.2 and section 3.2.

2.5 General Overview of the Causes of Myopia

A very schematic overview of possible paths to myopia is shown in Figure 6. Each of these possibilities could be greatly expanded.

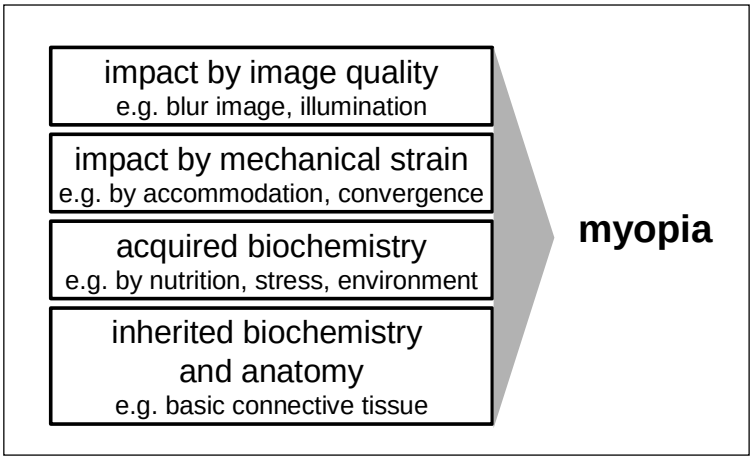


Figure 6 The potential paths to myopia

From the fact that under the same external conditions (i.e. near work, illumination etc.) not everybody gets myopic it can be concluded that the influence of the personal biochemistry / personal anatomy plays a deciding role.

In general, the importance of a proper refraction – especially for children – cannot be overestimated (see section 1.11).

3 Myopia – Observations and Experimental Results

This section contains:

Environmental, behavioral or biochemical parameters found to be connected with myopia

Therapies that have been proposed to prevent myopia or progression of myopia.

As there are sometimes interactions between these individual issues, a certain amount of repetition cannot be avoided.

Some observations and conclusions of the individual authors appear to be rather controversial. If we are to accept their observations as accurate, we must conclude that either

There is a connecting logic in the background which has yet to be revealed, or

There are various independent mechanisms, which have myopia as the common result.

3.1 Distribution of Myopia by Region, Age, Gender and Ethnicity

We can draw conclusions about the impact of different lifestyles, different environment, different nutrition, and different genetic heredity by comparing the variation in rates of myopia according to age in different regions. Some results are:

An evaluation of statistical data for reported blindness due to malignant myopia in different states of the USA was done by compiling a chart with the rate of myopia per state, and distance to seacoast, annual hours of sunshine and the nutritional concentration of calcium, fluoride and selenium in each state. The results were:[96]
- less **sunshine**,
- less **calcium**,
- less **fluoride**,
- less **selenium** and
- closer to a **seacoast**

resulted in a higher probability of malignant myopia.

Myopia rates are higher in urban than in rural areas[119, 120, 121].

Note:
Of course, farmers don't have much time to read.

The frequency of myopia at children in various countries is[122]:

- Germany - 10%,
- Taiwan, South Korea - 70%,
- Japan - 95%,
- Singapore - 74%[123],
- Mexico - 44%[124]

Myopia recently worsened as a problem, as stated by Lin et al.[125]: "In Taiwan, myopia was not a problem some 50 years ago"; today about 15% of the population have over - 7.0 D.

50 to 60 % of the Japanese are said to be myopic, but only 2 % of the people in South America are myopic[126]. The author of this publication hints at a substantial difference with respect to spontaneity between these two populations.

1971 to 1972 only 25% of the individuals in the USA were myopic, 1994 to 2004 this number increased to 41.6%[127].

The incidence of myopia in Japan was increasing from 15% in 1920 to 36% in 1940 to between 50 and 60% in 1985[126].

Sherpa and Tibetan children in Nepal have the same ancestry and genetic history, but the prevalence of myopia is 2.7% for Sherpa children and 21.7% for Tibetan children[128]. This difference was attributed to more rigorous schooling and higher advanced technology in Tibet.

Note:

Generally more rigorous schooling and higher advanced technology are going hand in hand with a change in nutrition and increased mental stress. For the impact of nutrition on myopia see section 3.24, for the impact of stress see section 3.19.1.

Results of a study on Eskimos[129] are shown in Table 2.

Age	% Myopic
Over 50	0%
41 to 50	Less than 5%
31 to 40	23%
26 to 30	43%
21 to 25	88%

Table 2 Percentage of myopes among Eskimos

Data about the degree of myopia in various populations[130] are shown in Table 3.

Population		Low myopia -1.00 to -5.00 D	High myopia -5.10 to -10.00 D	Extreme myopia more than -10.00 D
Asia, age 5 to 65[131]	Chinese	41%	14.7%	0.8%
	Malays	37.8%	8.5%	3.0%
	Indians	34.3%	7.7%	0.9%
USA, age 4 to 74[130]		43%	3.2%	0.2%
North America, Sioux Indians, age 3 to adult[132]		32.4%	4.1%	

Table 3 Percentage of myopes among various populations

A study from 2001[133], giving the percentage of myopic males (at least -0.5 D) between age 16 and 25 in Singapore:

82.2 % Chinese

68.7% Indians

65.0% Malays

Another statistic from USA (children, age 5-17 years)[134] is shown in Table 4.

Ethnicity	Myopes (shortsighted)	Hyperopes (farsighted)
Asians	18.5%	6.3%
Hispanics	13.2%	12.7%
Whites	4.4%	19.3%
African Americans	6.6%	6.4%

Table 4 Percentage of myopes among various populations in the USA

Typical childhood progression rates were found to be between – 0.2 D and – 0.6 D in Europe and USA, and between – 0.5 D and – 0.8 D in Japan[135].

In spite of similar myopia rates of Malays and Chinese, the age dependent progression profile appears to be rather different[136].

Results from Singapore and Hong Kong show that myopia is 1.5 to 2.5 times more prevalent among adult Chinese than in corresponding European-derived populations, and that women have significantly higher myopia rates than men[137, 138].

Moreover, as stated by Choo[139], "...severity of myopia rises by about 1.5 D per year in Singapore children, compared with 0.5 D per year in US children."

The higher rate of female myopes is confirmed by results about Greek students: 46% female students, and 29.7% male students are myopic[140].

Dayan found[141]: "During the 13 years from 1990 to 2002, the prevalence of myopia significantly increased among the Israeli population. Although there was an association with the level of education, gender, ethnicity, and origin, the prevalence of myopia increased on an annual basis, independent of these factors."

Malays, Chinese and Indians in Singapore have a higher prevalence of myopia than the same populations of Malays, Chinese and Indians in Malaysia[142], which can be explained by the different environment, like requirements for extensive studying.

The urban generational axial length shift was estimated to be approximately 1 mm longer than that of the rural area. These results suggest different environmental effects on the ocular development in these two populations of Chinese children[143].

"The global burden of myopia is growing. Myopia affected nearly 30% of the world population in 2020 and this number is expected to rise to 50% by 2050."[144]

Note:

Generally, reports about an enhanced prevalence of myopia among certain ethnic populations like Chinese, Japanese, Korean and Jewish populations can hardly be interpreted as a potential genetic disposition: Among these populations with an enhanced prevalence of myopia frequently exists a traditionally very positive attitude for education, learning and reading with corresponding increased demand for near work and excessive accommodation.

A very comprehensive report about the prevalence and progression of myopia was published by the National Research Council of the USA[145].

The high **importance of the level of light** to which people are exposed was investigated by French AN et al., which reported[146]: "**European Caucasian children in Northern Ireland have a greater prevalence of myopia, hyperopia, and astigmatism when compared to children living in Sydney**. Risk factors for myopia such as parental myopia, parental education, and educational standards do not appear to explain the differences." See section 3.14.1 about the Impact of illumination on myopia.

A mathematical model for the prevalence and the incidence of myopia was established by PR Greene et al.[147]

3.2 Accommodation and Near Work

In principle, results and experiences about accommodation (that is, changes in lens shape for near work) are related to artificially negative-lens-induced myopia, and myopia which was induced by forcing the eye to permanent near focus (see section 3.3).

3.2.1 Experiences and Results

3.2.1.1 General Experiences and Results

Basically excessive near work has the identical effect and works the same way as experimental lens induced myopa (LIM), which was described in numerous publications.

In general the influence of near work alone is not easy to isolate, as extensive near work means extensive in-door work (often at **low levels of illumination**, see section 3.14.1), which is mostly connected with a **potential lack of vitamin D** because of a lack of exposure to sunlight (see section 3.24.3). Moreover, children who are interested very much in reading often have a **more introverted personality** (see section 3.19.2) and are less interested in **physical activities**.

There are numerous indications that people, who are doing extensive near work, i.e., who accommodate extensively, are more often myopic. Some observations are:

- The appearance of myopia at people in USA and Greenland coincides with the **introduction of universal schooling**,[148] and the rate of myopia of school children in Berlin depended very strongly on the **level of the school** they visited: the more advanced the type of school, the higher the rate of myopia. Rates were between 55 and 35%[149].
- The progression of myopia of school kids is **slower during summer holidays**[150, 151, 152].
- Comparisons between myopia rates in 1882 and 1964 showed that the rate is very different for **individual professions**[93] (students in the 30% range, unskilled workers in the 2 to 3% range): While the total rate of myopia was increasing, the myopia rate for all the individual professions

except unskilled work was decreasing. Explanation: The overall increase in myopia, according to these results, can be largely attributed to a changed ratio of job distributions from unskilled work towards professional and office work.

Highly elevated rates of myopia were found for craftspeople of various professions, who have to do extensive near work, e.g. for typesetters (in year 1930[153]), tailoring (in the years 1953[154] and 1961[155]). Up to 77% of the persons in these professions were found to be myopic.

A test with monkeys (already in 1961)[156], whose **visual space was restricted** to an average of fifteen inches distance, showed that all of them developed some myopia.

There are indications that extended accommodation can create a **chronic spasm of the ciliary muscle**, and experiments on monkeys showed that this stretching will begin after spasms for 2 to 4 months so spastic myopia and axial length myopia exist at the same time[157].

Note:

A permanent load can damage any muscle, not only the ocular muscles[158, 159]*.*

A study of university students showed a strong relationship between reading and other near work with myopia was found, however no relationship between myopia and working on **video display terminals** (VDT) or watching TV[160]. Watching TV at close distance however was promoting myopia[161, 162].

Note:

These results appear to be contradictory. As will be shown in section 3.3 the effect of VDTs and TVs can be expected to depend largely on the quality of the displayed images. Due to the limited image resolution of TVs and VDTs (LCD screens are better) a watching of these screens from near distance will create a blur image on the retina, with the potential consequences as described in section 3.3.

For Chinese schoolchildren a correlation of myopia with the **reading** of books was found[163], in Finland a relation between myopia progression and time spent on **reading/close** work and on **reading distance** was found[164].

Rosenfield et al. stated[165] that "...results demonstrate that **myopes are less sensitive to the presence of blur**, and may at least partially explain why previous reports have demonstrated a larger **lag of accommodation**...". On the other hand, the compensatory eye growth in experimental myopia (see section 3.3) was **always in the right direction, even in the presence of very poor images**[166].

Rosenfield et al. stated[167] that "... findings do **not support** the proposal that the development of myopia in young adults is accompanied by a **reduced accommodative response** during near work."

Myopic children have less **tonic accommodation (i.e. dark focus accommodation)** than normal, i.e. emmetropic children[168, 169, 170]. After near work, however, the tonic accommodation of myopes increases more than for emmetropes. A large shift in tonic accommodation after near work was found to be typical for periods of acquisition and progression of myopia (some kind of accommodative hysteresis)[171].

Very contrary to these results is the statement by Kushner[172]: "**Overcorrecting minus lens therapy** for intermittent **exotropia** [see section 3.5] **does not appear to cause myopia.**"

Note:
*A potential explanation is that the risk is **not so much originating from the excess accommodation** caused by the negative lens, but by the **increased esophoria** caused by the negative lenses (esophoria means that the axes of the two eyes are adjusted too much inwards when accommodating). Esophoria is frequently associated with myopia (see section 3.5.1 about phoria).*

Near work, i.e. accommodation was shown **to increase the temperature** of the anterior segment of the eyeball, and to cause a **hyperproduction of intraocular fluid**[173].

Note:
This hyperproduction of intraocular fluid can increase the intraocular pressure; and an elevated ocular pressure was often found to correlate with myopia (see section 3.7.2). About the impact of the temperature on myopia see section 3.16).

Stress in connection with near work was made responsible for the development of myopia: It was stated that stress induces distant-accommodation, which conflicts with the actual task near-accommodation. This conflict was claimed to cause either a spasm of the ciliary muscle, or phoria[174] (phoria means the exes of the eye are not adjusted appropriately; see section 3.5 about phoria and section 3.19 about mental issues).

A helpful support of accommodation by **illumination** was found: see section 3.14.1.

Obviously **near-work induced transient myopia (NITM) is increased by mental stress**: see section 3.19.1.

Ip et al. found when examining Australian school children[175]: "**Although myopia was not significantly associated with time spent in near work after adjustment for other factors, there were significant independent associations with close reading distance and continuous reading.** These associations may indicate **that the intensity rather than the total duration of near work is an important factor."**

Langaas reported[176]: Children with myopia showed **greater instability of accommodation** (0.38 D) than children with emmetropia (0.26 D) at the 4.00 D target on Visit 1 and this instability of accommodation weakly **predicted myopic progression**.

An argument against the importance of near work was given by Jones-Jordan et al. who summarized their results[177]: "Before myopia onset, near work activities of future myopic children did not differ from those of emmetropes. Those who became myopic had fewer outdoor/sports activity hours than the emmetropes before, at, and after myopia onset. Myopia onset may influence children's near work behavior, but the lack of difference before onset argues against a major causative role for near work. **Less outdoor/sports activity before myopia onset may exert a stronger influence on development than near work**." See section 0 about the impact of outdoor activities on myopia.

When analyzing the reading habits of school children it was found that when starting reading the distance was about 28 cm, but after a while it decreased to just about 11 cm, which is too near for a stressless accommodation[178].

Li et al.[179] summarized the results of questionaires given to Chinese children. **Significantly associated with myopia was:**

- continuous reading (better not more than 30 minutes),
- TV viewing distance (better at least 3 meters),
- reading distance (better at least 30 cm),
- nib to finger distance (better at least 2 cm),
- head tilt when writing (better no tilt).

Li et al. reported[180]: Results: "**WD [working distance] and LI [light intensity] were positively associated with SER [spherical equivalent refraction]**. … When WD and LI were split up, the **detrimental threshold was approximately 40 cm for WD** and 6300 lux for LI."

In section 3.3.1 some research results are mentioned, where short intervals of relaxing the accommodation prohibited myopia or reduced the progression of myopia.

3.2.1.2 The Effect of Accommodation on Axial Length and Scleral Thinning

Accommodation causes a substantial **hysteresis of the ocular shape**: For normal people, after accommodation, as Walker et al. stated[190], "... **ocular shape had become more prolate [i.e. stretched]. This shape remained unchanged after 1 hour of sustained accommodation and then returned to baseline dimensions after 2 h of accommodation ... Ocular shape returned to baseline dimensions after 45 min of accommodative relaxation**."

It was measured (with partial coherence interferometry) that **the eye generally elongates during accommodation.** Drexler et al.[28] explained: "… by the accommodation-induced contraction of the ciliary muscle, which results in forward and inward pulling of the choroids, thus decreasing

the circumference of the sclera, and leads to an elongation of the axial eye length." and by Shum et al.[29]: "… the **elongation was more pronounced in emmetropes than in myopes**."

More results about increased axial length by accommodation are described in section 3.7.6

Mallen et al. reported[181]: "During relatively short periods of accommodative stimulation, axial length increases in both emmetropic and myopic young adults. **At higher levels of accommodative stimulation, a significantly greater transient increase in axial length is observed in myopic subjects than in their emmetropic counterparts**... The mean axial elongation with a – 6 D stimulus to accommodation **was 0.037 mm in emmetropes and 0.058 mm in myopes**."

Vasudevan et al. found[182]: "**EOMs [early onset myopes] and LOMs [late onset myopes] demonstrated larger NITM [near work induced transient myopia] than the EMMs [emmetropes] and exhibited NITM additivity [increased NITM after a second hour of near work], but the EOMs [early onsets myopes] also exhibited prolonged decay of NITM compared with the EMMs and LOMs. PMs [progressive myopes], but not SMs [stable myopes], exhibited additivity of NITM.**"

Note:
Isn't this a proof that myopes have a degraded connective tissue, which is lacking elasticity?

No association between parental refractive error of the parents and NITM magnitude and its decay time for the children was found by Lin et al.[183]

Collins MJ et al. summarized their measurements[530]: **"Small but significant increases in axial length were evident during and to a lesser extent, immediately after the accommodation task."**

Near work causes **not only accommodation via the ciliary muscle, but also a load on the oblique muscle, which handles the vergence**. A load on **this muscle can cause an elongation of the eye independent from accommodation** as outlined in section 3.7.3

EC Woodman-Pieterse et al. reported[184]: "… demonstrates the first evidence of a small but statistically **significant thinning of the anterior sclera during accommodation. These changes were more prominent in myopes** …"

Morgan I reported about experiments with chicken[185]: "**Eyes wearing negative lenses were significantly longer than fellow eyes by 25 h**, while eyes wearing diffusers did not differ from fellows until 72 h. By 48 h, the inter-ocular difference in lens-wearing animals was 5 times greater than in those wearing diffusers."

Notes:

Maybe this stretching of the eye which is caused by accommodation and which can be expected to be more pronounced at myopes (weaker connective tissue) is ***responsible for the accommodation lag of myopes due to some feedback mechanism between stretching and accommodation****.*

Section 3.17 describes that ***stretched axial length means reduced choroidal blood flow, where it is still open whether this reduced blood flow is a reason for further progression of myopia or just a consequence. The fact, that dopamine reduces the progression of myopia (see section 3.25.4) and increases retinal bloof flow*** *(see section 3.17)* ***is an indication that reduced blood fow just by temporal accommodation and stretching might be responsible for onset and progression of myopia.***

Temporal elongation means stretching and thinning of scleral tissue, and stretching of scleral fibroblasts is changing significantly the gene expression of these fibroblasts[186]*. This means,* ***accommodation has a direct impact of the biochemistry*** *of the eye; this builds a link between mechanical and biochemical models of myopia, and a link between functional and structural models of myopia as well (see section 3.7.1*

It appears to be very plausible that a temporal stretching of an already weak scleral tissue will result in a permanent stretching, thinning and elongation.

People with a high degree of myopia have a structurally weakened sclera and therefore the stretching caused by accommodation is very likely resulting in an additional structural weakening, which can be expected to increase the degree of myopia still more.

The conclusion is that especially people which are already substantially myopic should wear plus lenses for extensive near work, not only for the prevention of further progression but especially for the prevention of dangerous pathological changes of the sclera of the eye (see section 1.7).

The elongation caused by accommodation might be the reason of the accommodation lag of myopes – there will be permanent interworking between accommodation strength and related elongation of the eye. The reason of this transient increased elongation can be seen, however in a degraded structure of the connective tissue of the sclera. *(see section 3.3.2)*

3.2.1.3 The Effect of Accommodation on Image Quality

Harb et al. stated[187]: "Within subjects, **accommodative lags significantly increased with closer reading distances**, however there was no significant relationship between lag and refractive state. The variability in the accommodative response significantly increased with closer reading distances ... Increased lags and the variability in accommodation at higher accommodative demands **suggest that an increase in overall blur at closer reading distances might be related to the development of refractive state**."

In similar experiments, it was found that generally **at a reading distance of 30 cm no perfectly focusing accommodation is performed**[188]. The resulting degradation of the image quality can contribute to the development of myopia (see section 3.3 about the impact of a reduced image quality).

Schaeffel et al. summarized:[91]: "The current theory is that lag of accommodation during reading shifts the image plane behind the retina and thereby stimulates retinal neurons to release growth promoting factors that enhance scleral growth. This is thought to be mechanistically equivalent to the effects of a negative lens in animal experiments."

The accommodative lag is defined as the difference between accommodative demand and accommodative response. Thus, lag is directly the residual refractive error[189].

Note:
The word "growth" appears to be somehow misleading, ***as – at least for higher grades of myopia - there is no growth of structurally intact tissue (which is normally meant by the word growth), but a stretching of degraded tissue and a change of the biomechanical properties*** *(see section 3.3.2).*

3.2.1.4 Timing- and Hysteresis- Effects of Accommodation

Some results about the time it takes to accommodate and to recover are:

- Accommodation causes a substantial **hysteresis of the ocular shape**: With normal people, after accommodation, as Walker et al. stated[190], "... ocular shape had become more prolate [i.e. stretched]. This shape remained unchanged after 1 hour of sustained accommodation and then returned to baseline dimensions after 2 h of accommodation ... Ocular shape returned to baseline dimensions after 45 min of accommodative relaxation." (see section 3.7.4).
- Myopes showed reasonable **aftereffect of accommodation**[17], i.e. it took an average of 35 seconds for early-onset myopes and 63 seconds for late-onset myopes until the accommodation of the ciliary muscle was released. Non-myopes, however, showed no myopic aftereffect. It was

speculated that this transient pseudomyopia is either the cause or a precursor of permanent myopia [191].

Additionally, it was shown that during the progression of myopia there is a significant near work after-effect (sometimes called nearwork-induced transient myopia - **NITM**[17]), causing **transient myopia** that still existed 10 seconds and 30 seconds after the near task [192, 193].

Correspondingly, there is a reduced facility, i.e. a **reduced maximum frequency of accommodation**: "Mean distance facility was significantly lower (9.7 cycles per minute (cpm)) in the myopic group compared with the mean distance facility in the emmetropic group (15.6 cycles per minute). There was no significant difference in the near facilities of the two groups (11.5 cpm in myopes versa 12.9 cpm in emmetropes)."[194]

More recent experiments confirmed the fact that myopic children are showing a significantly larger near work-induced transient myopia, but demonstrated additionally that this **near work-induced transient myopia was still evident after 3 minutes, which is significantly longer than what was previously reported for adults**[195].

There is a **time lag of accommodation** for myopes [165, 196]. However, Rosenfield et al. stated[167] that "...stable myopes also exhibited the largest lag of accommodation." Mutti et al. found[197]: "Substantive and consistent elevations in accommodative lag ... did not occur in children who became myopic before the onset of myopia or during the year of onset. **Increased accommodative lag occurred in children after the onset of myopia**. Elevated accommodative lag is unlikely to be a useful predictive factor for the onset of myopia."

Note:
A simple explanation of this time lag can be seen in the fact that the eye is elongated by accommodation (see section 3.2.1.2): The sclera of myopes has a somewhat degraded stability, and at the moment the accommodation starts it is already partly compensated by this immediate elongation of the eye.

For children it is generally recommended *(**Note**: but very often not done)* to do the refraction after **applying a cycloplegic agent**. The residual accommodation, which exists if no cycloplegic agent is used results in **overcorrection of myopia** (see section 1.11).

Sivaraman reported[198]: "The magnitude of the NITM was higher in myopes compared to emmetropes for both five minute and 60 minute viewing time."

Note:
An explanation can be the degraded connective tissue of the sclera at myopes: In section 3.2.1.2 it was shown that accommodation causes the eye to strech temporarily, and according to Sivaraman's results this stretching is more pronounced at myopes.

Notes:

This aftereffect and hysteresis of accommodation can be responsible for a steady progression of myopia in school kids: If the kid has to change in class permanently and fast between near work and reading from the distant blackboard, the mentioned delay can give the impression that the current glasses are too weak. New and stronger glasses, however, can easily induce additional myopia as described in section 3.3, and these cycles can happen repeatedly. The long duration of the aftereffect (which was still evident after 3 minutes) strongly supports this model. Bifocal glasses might help in these cases, but care has to be taken when fitting these bifocals (see section 3.2.2.3).

Maybe the anomalies of myopic accommodation can be explained by a lack of nitric oxide (NO) in the smooth ciliary muscle (see sections 3.18.5).

*Open **question**: What is responsible for the time delay and the aftereffect of the accommodation, a muscular problem, or a hysteresis problem of the flexibility of the lens? It appears to be rather likely that **a muscular problem is a key issue for myopia, i.e. not a consequence, but a reason**.*

*Another explanation would be a **spasm of the ciliary muscle** of myopes during extended accommodation, which needs to take more time to disappear after the near work is finished.*

Maybe the hysteresis of the reshaping of the lens before accommodation and after accommodation contributes to this effect as well (see section 1.3.2.4).

3.2.1.5 Dark Focus and Accommodative Hysteresis

As mentioned in section 1.4.1 it is called dark focus when due to darkness there is no more accommodative stimulus.

Ebenholtz reported that when there was longer time of near accommodation before switsching off the light it can take many hours to release the existing near accommodation. He stated[199]: **"Since accommodative hysteresis implies a long lasting increase in ciliary muscle tonus, it is conceivable that the propensity toward hysteresis effects is related to the incidence of near-work induced myopia."**

Note:
It has to be concluded that reading or doing near work before going to sleep is extremely harmful.

3.2.1.6 The Strength of Accommodation

Some results about the strength and amplitude of accommodation of myopes are:

Abbot et al. stated[200]: "A **reduced accommodation** response to negative lens-induced accommodative demand was found in progressing myopes but not in stable myopes." In addition, eyes with myopia were found to have **lower amplitude of accommodation**.

Fong stated[201] "Eyes with lower amplitudes of accommodation must use more of their accommodative reserve for near work. Myopia may be an adaptation that develops in eyes with reduced accommodative amplitudes", and **less accurate** accommodation[202]. And a reduced accommodation was speculated to create a blur signal, which might be responsible for development of myopia[107]. Consequently, under-accommodation may precede the development of myopia as clinical data suggest[203].

Siegwart and Norton summarized earlier reports[204]: "Although there is disagreement about when it begins, progressing **myopic children tend to have a larger accommodative lag** [i.e. underaccommodation] than do emmetropic children."

Siegwart and Norton concluded[204]: **"… if eyes that are unable to use myopia to slow elongation are [**what is happening during normal emmetropization**], in addition, exposed to hyperopia [**i.e. a lack of sufficient accommodation**] through nearwork and underaccommodation, this might lead to myopia development."**

They add that additionally genetics plays a part, especially by the individual capability "to use myopia to slow elongation".

Note:
In other words, an overloaded and insufficient accommodation accompanies myopia, and has a high likelihood to be a main cause for myopia.
About "… to use myopia to slow elongation …": this should take place only if there is spent sufficient time without near accommodation.

It was found by McBrien et al.[205] that "...late onset **myopes having the largest amplitude of accommodation**, followed by early onset myopes, emmetropes, and hyperopes."

Note:
This might appear to be in contrast to the statements above; however, if one considers excessive accommodation as some kind of a cramp there is no more conflict.

Overall, these findings can be interpreted as a strong argument for plus lenses to avoid the onset of myopia.

In this respect, it is interesting that **wearers of glasses accommodate less and have lower convergence demands than emmetropes or wearers of contact lenses** due to optical reasons[206, 207, 208] (for – 5.00 diopters the difference is described as very roughly 0.50 diopters at reading distance). Moreover, hard contact lenses were often found to stop progression of myopia (not soft contact lenses, see section 3.26.1).

Some positive effects of **pharmaceuticals like atropine** can be at least partly attributed to their attenuating effect on the accommodation (see section 3.25).

Chinese people have lower amplitudes of accommodation than Caucasians[209], and **Chinese have a higher probability of becoming myopic**.

Notes:

*From an evolutionary point of view there might be a **linkage between both facts**:*

- *Without any accommodation the only one way to focus is to adjust the length of the eye as happens in emmetropization (see section 3.3.5), and for dominating near work this means to become myopic.*
- *Question: is there a rule like "the lower the accommodation before the onset of myopia, the higher the probability and the degree of the myopia that will develop later"?*

The paper "The Secret of Myopia (Near-Sightedness)" gives an easy-to-read and convincing description of the result of accommodation overload.[210]

For information about the related issue **tonic accommodation** (resting state accommodation) see section 1.4.1, the interaction between accommodation and convergence is discussed in sections 3.5.2 and 3.5.3.

3.2.1.7 Accommodation Spasm

Numerous authors claimes that an accommodation spasm is a problem when determining the refraction, and to avoid this spasm, e.g. cycloplegica like atropine are applied to relax the ciliary muscle (see sections 1.11 and 1.11.2).

As accommodation was found to cause an **elongation of the eye** (see section 3.2.1.2) is appears to be very plausible that an extended spasm of the accommodation will lead to an extended and rather likely permanent elongation.

This spasm, medical term asthenopia, is not disappearing easily, as Kajita et al. reported:[211] "… results suggested that the ciliary muscle was also actively working in asthenopia caused by accommodative spasm even if the patient was looking at a distant target."

In more detail, Kanda et al. reported[212] " The average ± standard deviation refractive power in the patients was significantly more negative than that in the healthy subject (-3.12 ± 1.06 vs. -1.49 ± 0.17 D). … The **spherical aberration** in patients was more negative than that in the healthy subjects".

Ninomiya et al. came to similar results[213]: " Excessive accommodative tone is manifested objectively by negative spherical aberration in eyes with accommodative spasm."

On one hand, the spasm has obviously a negative mechanical impact on myopia, on the other hand the reported spherical aberration can or will contribute independently to myopia.

About the impact of spherical aberration and myopia, see section 3.3.9.

Another aspect of accommodation spasm was reported by Khatsukov[214]: " Blood and oxygen supply, respiration and cerebral cortex function especially those cortical parts in which visual analyzer is represented were studied in children and adolescents with myopia and accommodation **spasm**. It was found that **respiration function and oxygen regime in myopia children and adolescents are 2-3 years behind those in normal children and adolescents**. … 20-day interval hypoxic training in children and adolescents raised efficacy of the external respiration and circulation, normalized bioelectric activity. The majority of the patients improved their visual acuity up to complete normalization."

Note:
Obviously, any means, which will cause relaxation to body and mind, are helpful to avoid the onset or the progression of myopia, as an impaired respiration is frequently an expression of substantial tension of body and especially of mind as well.

3.2.1.8 Myopia caused by Hyperopia

Viikari summarized her experiences[215]: "Contrary to the textbooks, which devide refraction errors into tree groups the author believes that there is only one refractive error, hyperopia, together with its various grades. The myopia and astigmatism are distortions, artefacts, due to the correction mechanisms of the eye, the accommodation performed by the ciliary muscle with its autonomous innervation. Under continous strain, and presumable over-excibility the result may end not only to pseudo-myopia and pseudo-astigmatism but at the same time to over activation, a possibly sentization of the entire autonomic nerveous system."

In other words, according to this model the excessive accommodative stress caused by the hyperopia leads to rather permanent cramps of the ciliary muscle and to an accommodation-caused elongation of the eye (see section 3.2.1.2), which on the long run weakens the connective tissue of the sclera and results in myopia and sometimes-progressive myopia.[216]

It has to be noted, that when being hyperopic the accommodation muscle is strained even when focusing at distant objects.

This has to be considered together with the fact that about 80 percent of young children are hyperopic, and this hyperopia can increase until to an age of 7 to 8 years and decrease thereafter until to an age of about 19 to 20 years. It is still said that up to +1.5 or +2.5 D there is no need for glasses as there are no problems with reading [217].

This traditional view, however, does not take into account the tremendous load on accommodation and its corresponding force to elongate the eye – see section 3.2.1.2. The large range of accommodation of children is only hiding the devastating long-term results of this over-accommodation.

The bad habit of children to work "with the nose on the paper", i.e. to work at too close distance because of their smaller body worsens the situation.

Notes:

- *Trivial analogy: a rubber band, which is stretched too much, will finally loose its elasticity and become too long. Clearly, plus glasses for near work would eliminate the early onset of myopia in all these cases.*
- *·The process of creating myopia by accommodation can be simply interpreted as a control-mechanism of emmetropisation (see section 3.2.1.14.*
- *·On the other hand, rather many people are not becoming myopic in spite of excessive near-work, which indicates* ***that biochemical effects like the dopamine metabolism (see section 3.3.3) are essential, too.***

3.2.1.9 "Screen sightedness" by SmartPhones and Tablet-PCs

As there is a connection between accommodation effort and myopia as outlined above it is obvious that the recent and extensive use of smartphones and small tablet PCs with their small fonts and a resulting close reading distance will have a strong negative impact on the onset and progression of myopia.

Allamby[218] reported some warning facts about the extensive use of smartphones and small tablet PCs:

"… there has been a 35 per cent increase in the number of people with advancing myopia (short sightedness) since the launch of smartphones in 1997. He has warned the problem could increase by 50 per cent in the next ten years." and

"… the average smartphone user holds the handset 30 cm from their face - with some people holding it just 18cm away - compared to newspapers and books, which are held 40cm away from the eyes."

Hansen MH et al. reported[219] about myopia prevalence in a Danish cohort aged 16-17 years and its relation to use of screen-based electronic devices that the use of screen devices >6 hr/day was associated with an increased overall risk for myopia by a factor of 2 compared with screen device use <2 hr/day.

S McCann et al. reported[220]: "Multinomial logistic regression revealed that **myopic refractive error was statistically significantly associated with increasing daily smartphone data usage** (**odds ratio 1.08, 95% CI 1.03-1.14)** … Seventy-three per cent of students believed that digital technology may adversely affect their eyes."

3.2.1.10 Aniso-Accommodation

For the case, that the object, which is looked at has a different distance from each eye Charman stated[221]: "It is shown that the asymmetric convergence caused by the changes in fixation required to read a line of text results in unequal accommodation demands to the two eyes. Since experimental evidence suggests that the required aniso-accommodation response cannot be achieved, and that accommodation in both eyes tends to match the response to the lower of the two demands, in general the retinal image in at least one eye must be out-of-focus."

This effect can result in a risk particularly for children, which are reading in unfavorable positions, i.e. lying on the side when reading (common when reading in bed). Correspondingly, it was reported that when children are tilting the head when writing this favors myopia[179].

Charman stated the conclusion[221]: "...maintain a symmetric posture and ... keep working distance as long as practicable."

3.2.1.11 Is there a Connection between Blur Sensitivity and Accommodation Deficits?

As the detected blur of an image can trigger the accommodation function there is the possibility that the reduced blur sensitivity of myopes is the reason for deviations of the accommodation performance.

The results are, however, contradictory:

Rosenfield et al. stated[165]: "These results demonstrate that myopes are less sensitive to the presence of blur, and may at least partially explain why previous reports have demonstrated a larger lag of accommodation in this refractive group."

Schmid et al. stated[222]: "There was no correlation between blur thresholds and refractive error magnitude, refractive error progression over the past year, or contrast sensitivity."

Note:
The reason for the contradictory results must be seen in differences in the setup of the experiments.

3.2.1.12 Accommodation and the Nervous System

The ciliary muscle, which performs the accommodation, is triggered by actions of the sympathetic and the parasympathetic nervous system. The parasympathetic system is responsible for the contraction of the ciliary muscle, and the sympathetic system is responsible for the relaxation, as Holland stated: [223] **"In effect, the sympathetic system facilitates a rapid shifting of accommodation from near out to far – as one would expect in a "fight or flight" situation."**

In general, as Holland summarized other studies[223] **"... mental activity is accompanied by a shifting in accommodation towards far.**"

Correspondingly, Davies reported[224]: **"Increasing the cognitive demand led to a significant reduction in the accommodative response in all subjects."**

Note:

Obviously, ***near work, which requires mental concentration creates a conflict: The mental activity triggers accommodation for far, the near work requires accommodation for near. Plus-glasses for near work should be able to solve or at least reduce this conflict.***

There are two different hypotheses about the nervous system existing, both supported by numerous papers, as Chen CJ, Schmid KL and Brown B reported[17]:

Myopia is caused by "a deficit in the sympathetic innervation."

Myopia is caused by "a deficit in the dual [i.e. both sympathetic and parasympathetic] innervation."

The nitric oxide (NO) metabolism plays a role in the functioning of the sympathetic and the parasympathetic nervous system[225]. Results with respect to the connection between NO metabolism and myopia are discussed in section 3.18.7.

Additionally, in section 3.2.1.7 it was mentioned that there is a linkage between accommodation spasm and respiration, which indicates an involvement of the nervous system.

Note:
In general, near work will always be accompanied by a significant mental concentration, which by itself (not talking about the accommodative stress), will always create some mental stress.

3.2.1.13 Accommodation and Biochemistry

Rada summarized[360]: " ...the chick choroid [the layer between retina and sclera] undergoes a rapid and dramatic increase in thickness in response to myopic defocus. This thickness change may be the result of changes in choroidal blood flow...**or by the contraction and relaxation of non-vascular smooth muscle cells present within the choroidal stroma**. It is hypothesized that choroidal thickening is a rapid mechanism for reducing the refractive error, by pushing the retina to the focal point. Concomitant with choroidal thickening, the rate of vitreous chamber elongation slows dramatically, as does proteoglycan synthesis in the chick sclera."

In other words, near focus initiates multiple biochemical processes, and it is likely that contractions of smooth muscles are involved. The ciliary muscle, which is responsible for accommodation, consists of smooth muscle fibers.

See also section3.30.2 about the interworking between mechanics and biochemistry.

3.2.1.14 "Emmetropization" towards Myopia via Accommodation?

In section 3.3.5 it will be discussed “Emmetropization towards Myopia via Image Quality”. There might be a similar effect caused by accommodation:

The length of the human eye increases from birth on[226]: “This length averages 17.3mm at birth. This averages increase to 20mm at one year of age. Then 22 mm at three years of age. The eyes stop to grow between 8 and 13 years of age, at the average length of 23mm”. This fact should be the reason that 90% of children under an age of ten years are hyperopic, i.e. their eye is (still) too short[78].

Emmetropization is the process, which causes the eye to adapt its optical properties to achieve best vision. This process is taking place mainly at very young age[204].

Notes:
Excessive accommodation at young age can therefore be considered as contributing substantially to the onset of myopia, and the use of plus lenses at a higher age when the myopia is already established has a rather limited success rate only.

As was said before (see section 3.2.1.1), accommodation causes the eye to stretch. Therefore, it might be possible, that this accommodation is partly responsible for the stretching of the eye during the growth of children, and that and excessive accommodation during this time might cause excessive stretching and permanent degradation of the connective tissue of the sclera, i.e. progressive myopia.

*The author of the Myopia Manual did not find this causality being published before, but it appears to be a possibility**. It would add a strong reason for children to use plus glasses for near work.***

Results about biochemical processes during emmetropization and the build-up of myopia are not contradictory to the mechanical model, as every mechanical impact on body structures generates biochemical processes.

As a reason why myopia would be caused by signals to the retina only and not by simple mechanical reasons the literature[396] mentions that myopia can be created by closing up an eye (form deprivation myopia, FDM). In section 1.4.1, however, it is described that even in darkness a residual accommodation may exist.

Results published by Metiapally and McBrien when working with tree shrews could be interpreted as support for this thesis[227]: "**Constant +4 D lens wear produced +6.9 D relative hyperopia**, while +6 and +9.5 D lens wear did not induce hyperopia. Lens-induced defocus changes in refractive state were significantly correlated with vitreous chamber depth changes."

In other words, plus lenses were working in the opposite direction as excessive accommodation or negative lenses, as long as their power did not exceed a certain threshold when focussing is no longer possible.

These **results from research coincide with results from life-long practical experience** by Viikari[41] Her statement was[262]:

"What else would myopia be than emmetropization, which has ended up exceeding the zero point provoked by long-term accommodation!" (see section 1.11 where some of Viikari's experiences are shortly outlined).

Whereas emmetropization by mechanical stretching is just a hypothesis, the "official" scientific result is described in section 3.3.5 "Emmetropization towards Myopia via Image Quality".

3.2.1.15 Myopia before Modern Times

Besides, the fact that we are genetically adjusted to an ancient environment where extensive near work like to day did not exist, in the time before glasses and optical examinations became common this situation has to be considered:

Only nowadays at a time of extensive schooling it is required that perfect vision is necessary for short **and** long distance at the same time – children have to do near work and at the same time being able to read everything at the blackboard properly.

In previous times when people like craftsmen became myopic because of extensive near work there was no need for perfect vision at distant, and they did not get minus glasses which would increase the accommodative load when doing their near work. As a result, the myopic increase of the length of their

eyes became stable without any more progression – the length was simply adjusted to their visual habits and stayed like this.

3.2.1.16 Summary of Results about Accommodation

Quite a number of people react with myopia when exposed to extensive near work and accommodation, and myopes have an accommodation problem.

The question is still[228], **whether myopia is caused by**:

Too strong accommodation, i.e. near work, potentially at a **too short working distance**

Too weak accommodation (under-accommodation), by which the focus is put at a distance behind the retina – at least temporarily, or **accommodation hysteresis,** i.e. a delayed relaxation of accommodation after near work

The impact of the accommodation-caused **temporary stretching of the sclera on the biochemistry of the sclera** (see section 3.7.1)

The **reduced image quality** caused by accommodation (see section 3.2.1.3)

An unbalance of the vergence system (vergence is the adjustment of the axes of the two eyes to each other according to the distance of the object, see section 3.5)

Too weak connective tissue to cope with the extra stress on this connective tissue during accommodation

An overreaction on the imaging effect, which accompanies (potentially inadequate) accommodation (see section 3.3)

Abnormal physical or physiological properties of components of the eye

Apparently, however, near work creates myopia only in connection with other, so far in detail still unknown processes.

Moreover, the reason for myopia can be rather specific, i.e. **different for different people, and different for different grades of myopia.**

**There is the saying:"...any system, under stress, will adapt to that stress,
in the direction of the stress, to accommodate that stress."**

Note:
The nowadays-excessive use of smartphones and small tablet-PCs causes excessive long-time accommodation as the writing on these gadgets is rather small and the reading distance is rather near. Therefore, a corresponding increase in myopia appears to be very likely.

3.2.2 Proposed Therapies Based on the Focusing and Accommodation Issue

3.2.2.1 Relaxing and Exercising

The first one who published experimental results about the interworking between accommodation and myopia as early as 1840 was Berthold who already designed a device called myopodiorthoticon at this time[229].

According to the "Bates – method" (Bates was an American ophthalmologist, first introducing his method in 1903) the prescription of glasses, with which a full correction is achieved, is accelerating the progression of myopia[230, 231, 232]. This idea, which was claimed to be based on experience, was promoted at approximately the same time by the German ophthalmologist Wiser (around 1900)[233], and the American ophthalmologist Raphaelson [234] applied a similar approach.

Their basic ideas, still supported today by many publications and classes[235 ,236, 237, 238, 239]:

Make regular **relaxing exercises** of the eye: Exercise the ciliary muscle and all the other muscles which move the eyeball – make training to see distant objects in a relaxed way, as Attenborough stated[230] **"... re-learning the art and skill of seeing** ... good sight is the result of a relaxed state of mind and body ... poor sight is the result of tension...". Seeing is actually considered to be strongly connected with the personal mind.

Notes:

- *This sounds a little bit esoteric, but what is happening in **the mind is having a strong impact on the body's biochemistry**. Therefore, as the biochemistry has definitely an impact, the modification of the mind must have an impact as well.*

- ***However, this is a two way process: biochemistry has an impact on the mind as well.***

Do "bathing in **light**" as an exercise, and make an exercise called **palming**, in which the palms of the hands cover the eyes to use transitions from full darkness to illumination.

Avoid full correction of myopia, and avoid using your glasses as frequently as possible (see section 3.2.2.3). The proponents of this method claim to have very positive results.

Note:

The positive results rise the question, whether they can be explained by the mechanical theories mentioned in section 3.7.

(Parson, a critic of the Bates method writes[240]: "The Bates Method relies for its effect on the activity of the eye pupil. All the Bates drills, such as palming, blinking, flashing and the concentration of the mind on nearby objects in the imagination drills, encourage the contraction of the

pupil. This contraction increases the depth of field of the lens and hence improves visual acuity. As it is temporary, there is no permanent improvement in vision.")

Optometrist Bowan[241] recommends therefore **the following easy exercise**: "After 20 or 30 minutes of close work, look away from your work to something that has printing on it, like a clock, a poster, a sign outside the nearby window – whatever target you have that has a notable detail on it. While staring at the details, numbers or lettering, tighten your toes downward inside your shoes, then progress up your legs, through your torso, fists, arms and neck, tensing all your muscles intently for about five seconds and then quickly release them all at one time … (The technical explanation for why this works is a basic fact of the brain that when you stimulate the voluntary nervous system as you did, the involuntary system is forcibly relaxed)".

The Bates method actually goes beyond the exercising of accommodation; it is also a method to fight the negative effect of stress on the eye (for more specific reports about the impact of stress on myopia see section 3.19).

The claim of some people that real axial myopia (not pseudomyopia) **can be really reversed** is very strongly rejected by the scientific world, and hardly any hard facts for this claim can be presented.

Notes:

- *Also with respect to the relatively new results presented in the next section it **makes sense to do some exercise** for accommodation and relaxing! There is a difference, however, between concentrated gymnastics of the eye and occasionally relaxing during near work. Additionally, the hysteresis of accommodation offers good reasons for these relaxing exercises (see section 3.2.1 about accommodation, section 3.7.6 about ocular shape and section 3.7.4 about the ocular lens).*
- *A clearly elongated eye cannot be made shorter by the proposed exercises, but there appears to be a good chance to avoid overcorrection and therefore a progression of myopia.*
- ***It is not only the long-term accommodation, which accompanies the extended near work, which is common today; it is also the long-term adjustment of the eyeball into one direction only. Maybe this lack of load-change of the respective extraocular muscle system adds to the development of myopia as much as the excessive accommodation.** Bates' exercises take care of this effect as well. In section 1.3.2.4 a theory of accommodation is described, which connects myopia and the extraocular muscles.*
- *Some followers of the Bates method seem to ignore scientific results instead of **synthesizing their personal experiences with research findings** (as is attempted in this book).*
- *In fact, it looks like the basics of these methods are **confirmed by recent scientific results**, but sometimes the somehow esoteric and rather emotional promotion of some followers is misleading.*

The partly related method **vision training**, also called **vision therapy, visual training, behavioral optometry, developmental optometry**, is described in section 3.15.

Commercially, there is a treatment called "NeuroVision" on the market, in which computer based exercises are performed for 10 to 12 weeks[242, 243].

It has to be emphasized that deliberate relaxing and exercising does not necessarily lead to the real and necessary relaxation, which is not only a physical state but a state of the mind as well.

3.2.2.2 Biofeedback

"The key is biofeedback, defined as a technique wherein a patient learns to control a bodily process or function of which he is not normally aware."[248]

The results of biofeedback exercising[244] are said by most authors to be **limited to improving** "**visual acuity**", but **with little effect on refraction, i.e. the myopia**[97, 245, 246]**.** Trachtman, however, reported **positive results**[247]: "The results showed a median 1.00 Diopter reduction in myopia after an average of 19 training sessions, with an average improvement in uncorrected visual acuity from 20/170 to 20/32."

In the light of the results about image quality (see section 3.3) this improved visual acuity, however might be able to avoid the progression of myopia.

There is a (rather expensive) "Accommotrac® Vision Trainer" on the market[248], which uses the biofeedback principle.

Notes:

- *There is the claim of Accommotrac®: "Blood pressure and heart rate, for example, can be controlled; so can the ciliary body." Not only this statement will get little approval from cardiologists, but also myopia involves far more than the action of the ciliary muscle. Therefore, the use of this device is questionable.*
- *The fact that biofeedback appears to improve visual acuity, but not refraction reminds of computer software, with which the sharpness and the contrast of copies of an images can be improved, but – naturally – the "real" picture cannot be improved. How about if biofeedback works somehow similar? Evaluation of the retinal image is improved, but the retinal image itself stays as before (i.e. no change in the refraction).*

3.2.2.3 Undercorrection for Near Work, Plus-, Bifocal- and Progressive-Glasses

For information about **permanent** undercorrection, see section 0.

3.2.2.3.1 General Results

Maybe the first one who promoted the use of plus glasses against myopia was Raphaelson about 100 years ago[249].

The principle of this treatment is to avoid full correction, i.e. to **avoid full accommodation** for (extensive) near work – it was already mentioned in sections 1.3.2 and 3.7.6 that the **eye elongates during accommodation, which corresponds with axial myopia**.

As a consequence excessive accommodation and the corresponding spasm of the ciliary muscle results in an increased risk for retinal detachment (see section 1.7), and a faulty refraction which does not consider pseudomyopia (see section 1.11.)

The fact that a high number of children under an age of ten years is (still) hyperopic is another reason to apply the concept of plus glasses. For information the general issue refraction see section 1.11.

The concept that plus lenses for near work might help against the onset of myopia in many cases and that undercorrection for near work might help against the progression of already existing myopia follows rather straightforward from the facts that:

- **Extensive accommodation and its various negative side effects can be reduced** by plus additions (see section 3.2.1 about accommodation)
- **Experimental myopia can be caused by extensive accommodation** (see section 3.3 about the effects of image quality)
- **For children, reading means extensive accommodation, learning and heavy stress** (see section 3.2.1.12 about accommodation and the nervous system and section 3.19.1 about the relation between stress and myopia)
- Plus-lenses (or plus additions) are effective not only when applying for near work, but also to **avoid accommodative spasm during refraction**: a spasm of the ciliary muscle during refraction can result in the prescription of minus glasses for myopes where in fact there is a **hypermetropia**, which requires the prescription of plus glasses.[41]

The following methods for undercorrection are used:

- Usage of **glasses with less power** for extensive near work

Usage of **bifocal glasses** (the top part of the glasses is adjusted for distant vision, the bottom part is adjusted for near work and has less power, i.e. some plus added

Usage of **progressive glasses** (similar as bifocal glasses, but there is a step-less transition between the part for distant vision and the part for near vision)

Usage of **plus glasses** for extensive near work, **together with contact lenses**, which are fitted for distant vision.

Usage of **bifocal contact lenses** (an add power as low as + 0.50 D was reported to be efficient)[250].

The relationship between the power of the addition and the reduced strength of the accommodation is shown in the following Table 5:

Power of the addition in diopter	Distance at which an accommodation for "infinity" is achieved
+ 0.50 D	2.00 m
+ 1.00 D	1.00 m
+ 1.25 D	0.80 m
+ 1.50 D	0.67 m
+ 1.75 D	0.60 m
+ 2.00 D	0.50 m
+ 2.25 D	0.45 m
+ 2.50 D	0.40 m
+ 3.00 D	0.33 m
+ 3.50 D	0.30 m
+ 4.00 D	0.25 m

Table 5 Power of the plus-addition versa reduced strength of accommodation

Common additions for near work are between + 1.0 D and + 2.0 D, but as well lower numbers[251] (between + 0.20 D and + 1.28 D) as well as higher numbers[41] (+ 3.0 D to + 4.0 D) were recommended).

The issue "undercorrection for near work" can be viewed as a simple problem of the ocular muscles, which are responsible for accommodation, and appropriate emmetropization. It can, however, as well be viewed as a neurological issue. Bowan summarized[252] the **stress caused by reading and the positive effect of plus lenses** on it: "It actually provokes an avoidance response much like the "fight or flight" re-

sponse: the heart rate increases; the pupils dilate; respiration can increase; adrenaline is produced; the perspiration rate increases - just as if an emergency were occurring. Two studies demonstrated this (Harmon, Pierce) and also that reading lenses *decreased* these responses." According to this model, the effect of the plus lenses with the prism is that the stress is reduced by moving the object far enough away (for more information about stress and myopia, see section 3.19.1.)

The results about **emmetropization** lead to the conclusion by Wildsoet[253] that "**full refractive correction of myopia will lead to accelerated progression**" **Fitting lenses with zero power in front of myopic eyes, however, led to a recovery from myopia, whereas the application of corrective glasses, (like the fitting of glasses which is usually done!) prevented the recovery from myopia**[254] (see also section 3.3.5 about emmetropization).

This principle of **undercorrection for near work** was **found to result in a substantial reduction of the progression of myopia, or even in a reduction of myopia**[255, 256, 228, 257, 258, 259, 260, 261, 262, 263, 264, 265].

In other studies and papers, however, the positive results could not always be confirmed[14], [228, 266, 267, 268], or showed a positive effect for the first year of the treatment only[269]. A documentation of various studies showed sometimes-positive results and sometimes no significant difference for bifocals[270]. A potential explanation for these negative results is given in section 3.9

Some individual results are:

In detail Morgan stated[99]: "The COMET study reported that the progressive addition lenses were **more effective with children with lower myopia**, lower accommodative responses and closer reading distances, and **less effective with children with higher myopia**, better accommodative responses and longer reading distances."

Gwiazda summarized results of this COMET study when comparing the effect of progressive addition lenses (PALs) with a 2.0 D addition and single vision lenses (SVLs)[271]: "The main result was a statistically significant but clinically inconsequential 3-year treatment benefit of PALs of 0.20 D ... Additional analyses showed that children with reduced accommodative responses and near esophoria had a larger treatment effect (0.64 D)."

Notes:

*This matches with my suspicion that cases of **lower myopia are caused primarily by an "over-emmetropization" by intensive near work** (see section 3.3.5), but that cases of **higher myopia are caused primarily by defects of the connective tissue** (see section 3.30 for corresponding*

conclusions about the treatment). Clearly, both effects will be frequently or even mostly combined.

Besides bifocal glasses bifocal contact lenses with a +2.00 D add gave positive results as well, as Walline et al.[272] reported: "Soft multifocal contact lens wear resulted in a **50% reduction in the progression of myopia and a 29% reduction in axial elongation during the 2-year treatment period** compared to a historical control group."

An experiment with identical twins was published, comparing the results of singlevision soft contact lenses and progressive spectacles, showing a positive effect of the progressive glasses[273].

Plus glasses have a prismatic effect as well, which has an impact on the vergence mechanism[274], i.e. they are **reducing esophoria**[275] (vergence is the adjustment of the axes of the two eyes for proper focusing at the respective distance, esophoria is a fault in this adjustment, i.e. the axes are too much inwards; for details see section 3.5).

It was reported that plus glasses were successfully applied already at children at age three[276].

(Due to their small body size children are doing near work at an extremely short distance very frequently)

Ophthalmologist Viikari summarizes her lifelong experience by the recommendation of additions of even as high as + 3.0 D[262].

Consequently, for people who are wearing low power glasses the recommendation is to take them off for extensive near work. For kids who are **not myopic yet**, but might be at risk, there are recommendations to **use plus glasses** for extensive near work, as Weale stated[16]: "...several studies suggest that the degree and **prevalence and early onset of myopia can be reduced worldwide by the early provision of reading glasses**. They are to be viewed less as corrections than as bars to accommodative excess. The obstacles to the implementation of the requisite health policy are cultural rather than scientific or economic."

Suemaru et al. found[277]: "The results of this study indicate that, compared with SVLs [single vision lenses], the PALs [progressive addition lenses] provide a similar level of comfort and compliance with spectacle wear for myopic children".

Li et al. summarized the results of several studies[278]: "A meta-analysis of nine of these trials showed that **MLs [multifocal lenses]** with powers ranging from +1.50 to +2.00D were **associated with a statistically significantly decrease in myopia progression in school-aged children compared with SVLs [single vision lenses].** The benefit was greater in children with a higher level of myopia at baseline and sustained for a minimum of 24 months. Asian children appeared to have greater benefit from intervention with MLs than white children.

Various studies gave mixed results for **bifocal (or progressive) glasses** [279, 280, 281]. Grosvenor et al. stated [282]: "... some showing myopia control with bifocals and some not ... there is evidence

that bifocals slow myopia progression in children with nearpoint **esophoria**, but not in children with **exophoria** at near [esophoria and exophoria are faulty adjustments of the axes of the two eyes for short distance – at esophoria the axes are too much inwards, at exophoria they are too much outwards, see section 3.5 for details]."

A 2-year study by Yang et al. with school children with a + 1.50 D near addition showed[283] "Compared with SV [Single Vision] lenses, myopia progression was found to be retarded by PALs [progressive vision lenses] to some extent in Chinese children ..."

Similar results were reported by Young[284].

Another trial showed that bifocals slowed the progression of esophoric myopes in the **first 24 months only**, but later on myopia progressed at a similar rate as for children with single-vision glasses; the previously achieved difference in the degree of myopia was maintained, however.[285]

The results of another trail by Cheng D et al were[286]: "Myopic progression averaged

-1.55 D … for those who wore single-vision lenses,

-0.96 D … for those who wore bifocals, and

-0.70 D … for those who wore prismatic bifocals."

Kowalski reported some initial problems when using the bifocals[287]: " One week after receipt of the study glasses, children wearing PALs [progressive addition lenses] showed a higher frequency of three visual symptoms related to adaptability: looking down from the blackboard and getting items on their desk in focus, blur when reading, and difficulty going down steps." However, "By 1 month, these differences disappeared and the frequency of all visual symptoms remained low and similar for both treatment groups".

Greene[288], [289] developed computer models to predict the refraction status over time making the case for reading glasses to stabilize College myopia.

3.2.2.3.2 Plus Addition, Bifocals and their Prismatic Effects

Maybe the "mixed results" for glasses mentioned above are caused mainly by the difficulties to fit the "right" bifocal or progressive glasses, take care of the very individual AC/C ratio (see sections 3.5.2 and 3.5.3) by prismatic glasses as well.

Generally, it is recommended to **combine the low plus lenses with appropriate prisms** to take care of the vergence[252] (see chapter 3.5.6 about additional prisms)

Viikari, however, summarized her lifelong experience as ophthalmologist that prism add-ons are not necessary for the plus additions[290].

Special care has to be taken when **fitting bifocals** to achieve the undercorrection for near work[291]:

The ratio of action between accommodation (A) and convergence (C), called the **AC/A ratio** can be upset in a negative way (see also section 3.5) – especially if just one power (e.g. +1.50 D) is added (see also section 3.5.2).

When using progressive bifocals the kids may **look through the wrong part** of the glasses without knowing it, i.e. to look at short distance through the upper part, which is fully correcting for distant vision. This cannot happen with presbyopes for which bifocals are normally fitted, because they can see clear through the right part anyway.

Therefore, special attention has to be paid to the setting of the **bifocal height**. According to their reading habits, the kids need bifocals set at the pupil, not level with the eyelashes as for adults.

Cheng D et al.[292] reported a significant reduction of myopia progression for bifocal spectacles with + 1.50 D additions and with an appropriate prism compared with bifocals without prism.

At experiments with chicks Nimri et al.[293] found that **part time wearing for at least 6 h per day of bifocal spectacle lenses had a significant positive effect on myopia control.**

3.2.2.3.3 Plus glasses – are they Effective via Reduced Accommodation or via Modified Vergence?

Wearing glasses (not contact lenses) has **not only an effect on accommodation, but generally also on vergence** (see section 3.5.5) – and vergence, **especially the esophoria** (see section 3.5.1) is closely associated with myopia.

From this point of view, there is a significant difference between an increased reading distance, an undercorrection, bifocals or progressive glasses, and plus glasses, e.g. combined with contact lenses if necessary.

Wearing of plus glasses was explicitly claimed to be effective against myopia[234, 238] (not only for prevention, but also for improving an already existing myopia) **and offers the best means to reduce the potentially dangerous esophoria.**

It has to be emphasized that plus glasses for near work do not take the **load from the oblique muscles which in this case take care of the vergence,** especially when the near work is done at rather short distance. Maybe some negative results of plus glasses can be explained by this load on the oblique muscles. In section 3.7.3 the effect of the oblique muscles on myopia is discussed.

Note:
The supporters of the plus-lens-therapy mainly argue on the basis of personal experience only without going into much detail of explanations, i.e. without mentioning its positive effect on vergence. ***There is, however, a scientific linkage between plus lenses, phoria/vergence, and myopia via the degraded-image-quality-model*** *(see sections 3.3 and 3.5).*

3.2.2.3.4 Bifocal and Multifocal Contact Lenses

Obviously, the situation for spectacle glasses with the plus addition at the lower part and for contact lenses with a concentric plus addition is very different:

- For spectacle glasses, the eye is not always focusing through the center of the glasses.
- For contact lenses, the eye is focusing always rather exactly through the center of the lenses.

A study with a pair of identical twins wearing soft contact lenses showed **positive results for bifocal contact lenses**, as Aller reported[294]: "The child wearing SVSCLs [Single Vision Soft Contact Lenses] over the first year showed significant myopic progression, increasing -1.19 D (binocular average), while the child wearing BSCLs [Bifocal Soft Contact Lenses] showed no progression (+0.13 D). The latter child showed limited progression (-0.28 D) over the second year, while switching from SVSCLs to BSCLs arrested progression in the other child (+0.44 D after one year). Axial length data were consistent with the refractive findings."

Walline et al. summarized their results for multifocal soft contact lenses[295]:"Soft multifocal contact lens wear resulted in a 50% reduction in the progression of myopia and a 29% reduction in axial elongation during the 2-year treatment period compared to a historical control group."

Lam CSY et al. reported[296]: "… myopia in children who wore the DISC [Defocus Incorporated Soft Contact] lenses [with an addition of +2.50 D] for five or more hours/day **progressed 46% (mean difference=-0.382 D, p=0.001; 95% CI -0.59 to -0.17) less than those in the SV** [Single Vision] group."

It was noted that for glasses the peripheral defocus is not very stable and that bifocal contact lenses should be preferred as for these the lenses are rather well centered in front of the eye, independent from eye movements[297].

Overall, as of 2014 reductions of myopia progression by soft multifocal contact lenses between 30% and 80% were reported[127].

As of 2015 Walline reported[298]: "… a recent randomized clinical trial fitted progressing myopic children with executive bifocals for 3 years and found **a 39% slowing of myopia progression for bifocal-only spectacles and 50% treatment effect for bifocal spectacles with base-in prism, al-**

though there was not a significant difference in progression between the bifocal-only and bifocal plus prism groups."

According to a summarizing report by Smith et al. [1031] treatment with for soft bifocals resulted in an average slowing of myopia progression by 48% (average of multiple independent trials).

JJ Walline reported[299] about bifocal contact lenses: "Adjusted **3-year myopia progression was -0.60 D for high add power [+ 2.5 D], -0.89 D for medium add power [+1.5 D], and -1.05 D for single-vision contact lenses.** The difference in progression was 0.46 D (95% CI, 0.29-0.63) for high add power vs single vision, 0.30 D (95% CI, 0.13-0.47) for high add vs medium add power, and 0.16 D (95% CI, -0.01 to 0.33) for medium add power vs single vision."

Hair et al. analyzed different concepts for multifocal contact lenses, i.e. center distance designs versa center near designs and reported[300] "… the center-near MFCL design caused hyperopic defocus at multiple peripheral locations, which is not hypothesized to slow myopia progression."

See section 3.3.11.1 about advanced versions of multifocal contact lenses.

3.2.2.3.5 Intermittent, Short Term Wearing of Plus Glasses

This issue is related to both accommodation and image quality as well.

To avoid a duplication of content, see section 3.3.6

3.2.2.3.6 Permanent Undercorrection instead of Undercorrection for Near Work only

The effect of permanent undercorrection appears to be still disputed, as some controversial reports show:

Permanent undercorrection might be harmful: Many followers of the Bates' method propose a **permanent undercorrection**. A trial, however, showed that a **permanent undercorrection of +0.75 D was increasing the progression of myopia** at children instead of slowing it down[301]. Similar resilts were reported by Vasudevan et al[302]: "Under-correction of myopia produced a small but progressively greater degree of myopic progression than did full correction. The present finding is consistent with earlier clinical trials and modeling of human myopia."

The authors of this paper mentioned above, however, state explicitly that their results apply for **permanent undercorrection only**, and that previous **positive results of progressive reading addition**[256] **are still valid**. Chung et al. wrote[301]: "Although we have shown that a general undercorrection of the myopia tends to accelerate the progression of myopia, it is significant that

a **full distance correction for myopia, taken in conjunction with a progressive reading addition, reduces the progression of myopia** (Leung & Brown)."

A **different interpretation of these results** was given by Eulenberg A[303]: He presented reasons that the first prescription have been an undercorrection, and that the first 6 months should be considered a "run-in" period. He concluded: "With the "6-month run-in" graph, we see that the difference in change in refraction over the last 18 months of the experiment is within the margin of error.... If the experiment had continued for another 12 months, the "undercorrected" group might well have come out with less myopia even without factoring out a run-in period.... during the last six months of the experiment, the "undercorrected" group progressed less than the "fully corrected" group."

Permanent undercorrection might have no effect: In an earlier and similarly designed study four groups were examined: full time wearers of glasses, myopes who switched from distance to full-time wear, distance wearers, and non-wearers. The result stated by Ong et al.[268]: "...that the 3-year refractive shifts are **not significantly different** among the four groups."

More recently, Adler et al. found:[304]: " **Undercorrection produced a slight but not statistically significant increase in myopic progression** over the 18-month period equal to 0.17 D, compared to full correction. A similar trend towards an increase in progression was noted in females and in children with near esophoria."

Permanent undercorrection might be helpful: Additionally, **to answer the question whether full correction or undercorrection are more suitable to reduce the progression of myopia**, schoolchildren were fitted with glasses where one eye was fully corrected for distance and the other eye was undercorrected by up to 2.00 D (monovision). As a result, Phillips found[305, 306]: "All children accommodated to read with the distance corrected (dominant) eye. Thus, the near corrected eye experienced myopic defocus at all levels of accommodation. **Myopia progression in the near corrected eyes was significantly slower than in the distance corrected eyes**." and "...**suggesting that sustained myopic defocus slows axial elongation of the human eye."**

Tarutta E et al.[307] made an experiment: **48 children aged 5–8 years … with emmetropia and risk factors of myopia development were prescribed the continuous wearing of plus lenses to induce myopia of 1.0 D. No cases of myopia onset were observed during the 9 -year follow -up period**." The control group, however, showed an increase in refraction.

Note:

Apparently it is important at which age the permanent undercorrection takes place – at young age, during the main emmetropization process ist works positive (as in experiments with animals), at a later age the result is negative.

There is some blur adaptation when people with myopia do not use full distance correction, as Rosenfield et al. wrote[308]: "A significant change in letter and grating visual acuity was observed during the course of the 3-h period of sustained blur..." and "However, no significant change in refractive error, measured using noncycloplegic autorefraction, was found. These results demonstrate significant blur adaptation in subjects with uncorrected myopia, which does not result from a change in refractive state. We hypothesize that the improvement in visual resolution results from perceptual adaptation to the blurred image, which may occur at central sites within the visual cortex." In other words, **people who do not use proper correction might feel they are improving their myopia, but in fact, they are not.**

As Bowan noted[309, 310], this blur adaptation can be explained by a so-called anti-aliasing[311] image processing by the brain (see also section 3.5.6).

Notes:

- *On one hand the result that undercorrection increases myopia matches the results given in section 3.3, where **optical blur**, which is a consequence of **permanent undercorrection, is shown to be a cause for myopia** as well.*
- *On the other hand the result that undercorrection reduces myopia matches the results given in section 3.3, where **plus lenses** caused the eyes of animals to shorten, i.e. to become **hyperopic**.*
- *Maybe the relation between the time which is spent for near work and which is spent for distant viewing could explain this conflict: It may depend simply, whether the eye can spend **enough time with successful focusing** (i.e. when it has a sharp image), or whether for a **very long time the eye detects a blur image only**.*
- *I feel that there should be simply reasonable ("enough") time of the day at which there is "perfect" focusing of the eye, and that accommodation during the day should not be completely eliminated (i.e. the accommodative system should not be completely out of action). Additionally there should be some time with an undercorrection to enable emmetropization against myopia. Therefore, success depends on your normal daily vision-environment.*

Permanent overcorrection is increasing myopia without any doubt (see section 3.3 as well).

Until there is a definite answer to the question about permanent undercorrection, the conclusion is that it is best for the eye:

- to have permanently a clear focus
- to avoid excessive accommodation load.

Obviously, bifocals are matching these conditions best, but it appears to be hard to make use of this concept, as there are some ophthalmologists, optometrists and opticians, who do not like to apply this concept, and these bifocals are not so easy to fit properly.

Therefore a solution without these bifocals is to use glasses with proper distance correction permanently, but to exchange them for glasses with a plus addition for longer time near work like reading, doing homework, making handicrafts, writing tests in school etc.

Very careful determination of **the right refraction** is therefore an extremely important issue (see section 1.11).

The onset and the progression of myopia cannot be explained by the process of accommodation alone; **of very high impact is the image quality as well**, therefore attention should be paid to sections 3.3 (The Effects of Image Quality) and 3.4 (Myopia by Accommodation versa Myopia by Image Quality).

3.2.2.3.7 Why is there no Agreement about the Usefulness of Plus-Glasses?

The **reported contradictory results** for the prevention of the onset or the progression of myopia could be based on these reasons:

The **detailed process** of the fitting of plus glasses or plus additions was different in the various studies. The use of cycloplegia (i.e. agents to relax the ciliary muscle) and autorefraction (i.e. automatic measurement of the refraction), e.g., can make a difference by avoiding overcorrection.

When using bifocals the position of the plus addition appears to be essential, as it was stated[265]: "The effectiveness of the bifocal in this study may well depend upon the very high position of the add fitted to the child. … **The bifocal fitted too low or too small a bifocal or a bifocal, which is not used, does not provide a proper test of the effectiveness of the bifocal**. Under reasonably well controlled conditions the bifocal appears to be effective in controlling the progression of myopia."

In this respective paper, it was reported "For the Caucasian subjects the annual rate across all age groups is -0.02 diopters for the right eye and -0.03 diopters for the left eye of the bifocal subjects. The control subjects have a mean annual rate of -0.53 for the right eye and -0.52 for the left eye …"

Plus-glasses worn at near work **do not take the load from the muscles, which are causing the vergence**, the oblique muscles. See section 3.7.3 for the effect of these muscles on the elongation of the eye and herewith on myopia.

Plus glasses do not necessarily reduce the permanent **tonic accommodation** (see section 1.4.1 about tonic accommodation).

The myopia of the involved persons was based on **different biochemical or mechanical/anatomic processes**.

One study, e.g., reports about significantly larger effects of progressive lenses at lower accommodative responses at near, and with lower myopia[269].

Note:
This decreased effect of progressive lenses for higher myopia can be explained by the conclusion that higher myopia is less determined by optical effects, and is more determined by an overall weaker connective tissue. Correspondingly, in these cases a strong emphasis should be put on systemic improvements, e.g. by nutrition.

Another issue, which might be responsible for the controvery about the efficiency of plus glasses, is the **peripheral defocus** as shown in Figure 7.

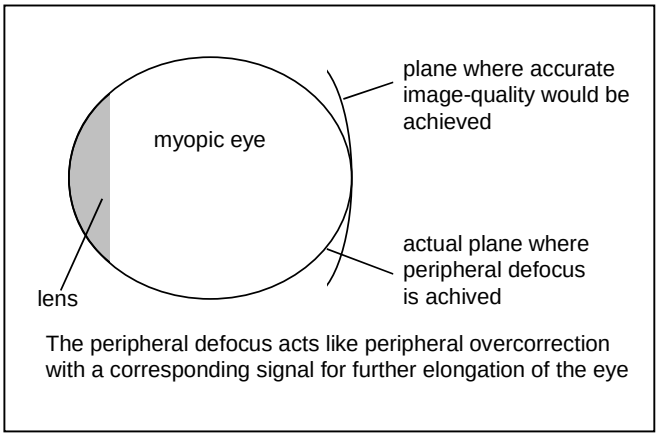

plane where accurate image-quality would be achieved
myopic eye
actual plane where peripheral defocus is achived
lens
The peripheral defocus acts like peripheral overcorrection with a corresponding signal for further elongation of the eye

Figure 7 The peripheral defocus

It shows that for glasses with perfect central vision there is a peripheral defocus which acts as overcorrection and makes a further progression of myopia rather likely.

The more stretched the eye is, the smaller is the radius at the back of the eye, and the larger is the peripheral defocus. The consequence is, that the higher the myopia is, the more pronounced is the negative effect of this peripheral defocus.

Obviously, undercorrection cannot solve this problem in general, as in this case there is a reduced image quality for distant vision in the center of the image plane.

For more information about peripheral defocus, see section 3.3.11

3.2.2.3.8 Is the Accommodation System Getting too Lazy by the Plus-Glasses?

There could be the argument that in the long term the lack of accommodative effort is making the accommodative system unable to work any more, i.e. to accommodate properly for near vision.

Notes:
Counter-arguments are:

- *Many people are doing hardly any near work during their daily life and they are still able to focus exactly for near if it is appropriate. Our ancient ancestors did not do nearwork of extremely long duration like for reading at all. On the other hand, they did fine handicrafts like embroidery, leather plaiting, flint chipping etc. – many dark winter days were spent like this.*
- *Even if plus glasses are used for extensive near work there are many occasions in daily life where short term accommodation for near is taking place without the usage of the plus glasses, which results in permanent training anyway.*

On the other hand, a lifelong underusage of accommodation might promote an early onset of presbyopia.

3.2.2.3.9 Plus-Glasses to Reverse Myopia?

In section 3.3.1 it will be summarized that not only by minus glasses artificial myopia can be generated, but also that by plus glasses hyperopia can be generated at animals.

Maybe an **intermittent wearing of plus-glasses, which is causing already a slight blurring**, might cause an effect like that at humans.

Viikari's experience as longtime ophthalmologist leads her to recommend **plus-additions of 3.0 D for near work**[262]. This might already have a slight blurring effect, which might explain her numerous positive experiences in preventing and treating myopia.

3.2.2.3.10 Plus Glasses or Undercorrection – a Striking Result

B Swiatczak and F Schaeffel reported[312] a striking result about an experiment with ten emmetropes and ten myopes: In almost all of the myopic eyes the retina no longer distinguishes between defocus blur imposed by positive lenses (which should result in more temporary hyperopia) and a lowpass filtering blur of an image (which generally promotes myopia). **As a consequence almost all of the myopic eyes reacted with elongation instead of shortening, which for most of the emmetropc eyes was the case.**

Note:

This means for myopes (but not for emmetropes) that using undercorrection for distant viewing creates a blur, which is in effect a form deprivation blur, which should promote myopia. Therefore this is an argument that permanent undercorrection is harmful for myopes.

What is the reason for this effect? Maybe it are the aberrations caused by the elongation of the myopic eye.

As a consequence there appears to be a difficult balance for myopes – as well some undercorrectio as well as some overcorrection can be a reason for progression of myopia.

Now the question is whether this behaviour of the retina of myopes is a consequence of myopia, or vice versa, myopia is the consequence of it.

For near work or reading, however, the positive effect of plus additions should not be affected.

Conclusion:

Every accommodation causes the eye to elongate temporarily (see section 3.2.1.2) and for children, which in general have a weaker connective tissue the elongation may become already permanent.

Plus lenses to relieve the accommodation are very helpful, but the moment myopia is established it can hardly be reversed. Therefore, providing children with plus lenses for near work is strongly recommended.

3.2.2.3.11 Plus Glasses – a Summary

Overall, the use of plus glasses (for non-myopes) **or plus additions** (for myopes) **for extensive near work** (best with appropriate prism) **offers an easy first step to prevent further progression of shortsightedness, or to prevent shortsightedness at all.**

Permanent undercorrection, however, is obviously harmful (see section 3.2.2.3.10)**.**

And still more logical, you must keep a proper distance for reading – even with plus additions! – the more distant the paper the better! A larger distance has the same effect as a plus addition (not counting the vergence effects which will be discussed in section 3.5)!

Therefore, always take care to avoid excessive accommodation, e.g.

- **by a general undercorrection of the contact lenses and the use of additional glasses for perfect distant viewing, or**
- **by full correction of the contact lenses and the use of plus glasses for near work, or**
- **by wearing bifocals**

Notes:

- *Maybe the claimed positive effect of plus glasses can be attributed primarily to the treatment of the esophoria (which is often associated with myopia, see section 3.5.1), and less to the reduction of load for the ciliary muscle by the accommodation.*

- ***Correspondingly, negative lenses and overcorrection with negative lenses increase esophoria***[172].

- *According to the generally and scientifically agreed fact of **emmetropization** (section 3.3.5), **accommodation** (section 3.2), accommodation induced **elevated IOP** (section 3.7.2) and artificially **negative lens induced myopia** (section 3.3) the positive effect of adding of plus power for near work **is convincing.***

- *As there were no negative results published for the use of simply adding some plus power for extensive near work, the recommendation should be: **Try it!***

- *If you want to try now the use of plus glasses for near work, you should get glasses from an optician who is fitting the glasses according to the geometry of your face, and **you should avoid the simple glasses from the shelf**. A report from a reader of this paper indicates that **unfitted glasses of this kind can lead to astigmatism**, a result that can be explained by the reduced image quality in certain regions of the retina.*

- *Astonishingly, **there is a lot of discussion about plus glasses and bifocals, but hardly anyone is talking about keeping a proper (i.e. not too near) reading distance! Doing near work with a larger distance, however, is equivalent with plus glasses and a shorter distance** (not mentioning the potentially disturbing vergence effect of a shorter distance, and the prismatic effect of plus glasses, see section 3.5).*

- *Nevertheless, it is **hardly likely that optical means like this undercorrection for near work alone are enough to fight pathological or progressive myopia**. It has to be supported by following the other recommendations, too.*

For **older people** there is another, additional mechanism of plus glasses / plus additions: With the beginning of **presbyopia** the lens loses flexibility, it "freezes" its shape (see section 1.4.3). A lens, which is mostly in the accommodated shape, stays in this shape even when the ciliary muscle is relaxed, resulting in the symptoms of myopia. As a consequence plus glasses / plus additions for near work should be helpful for these people, too, because they keep the lens in a more "far-distance-shape". On the other hand, if all the accommodation efforts are taken off from the lens, it is loses its flexibility still earlier.

Moreover, a device called "**Myopter**", which is designed to eliminate the accommodative effort, is sold[313].

Finally, especially for children **the seating position has an impact on the proper reading distance: if the chair is too low with respect to the height of the table the reading distance will be too short, and reading when lying on the belly results definitely in an inadequate distance**.

By the way, it was found that a "traditional" upright (90-degree) working position is not really recommended, and that a more relaxed, 135-degree ("slouch"-) position is clearly better for the spine[314]. This position results additionally in a larger distance between the eye and, e.g., the book or the computer.

As a conclusion to the difficult and complex situation which learning children are facing, Skeffington, who is the originator of behavioral optometry (see section 3.15 about behavioral optometry / vision therapy), stated[315]:

"To help children to learn, carefully prescribed learning lenses for use in the classroom are irreplaceable."

Or as ophthalmologist Viikari summarized her lifelong practical experience[316]: "... on starting prevention as early as possible ... **[children] should preferably been born with plus glasses on our noses**." and[41] "If the fight against short-sightedness is to have any chance of success, the first essential is to stop altogether the manufacture of ordinary whole minus lenses and make only half lenses or bifocals with plano lower parts..." and[317]:

"Once again: my main thesis regarding the prevention of myopia, is to start the prevention with plus glasses (in close work) beforehand, before there is any sight of minus and myopia at all!"

Note:
These experience-based recommendations are matching very well with science-based results like the one reported, e.g., in section 3.3.6

The emphasis here is very clearly on the prevention of myopia (and the prevention of progression of myopia) and not on any reversal of myopia.

Potentially **negative consequences of permanent (!) undercorrection** are discussed in section 3.2.2.3.6

3.2.2.3.12 Comparison of the Various Optical Methods

In Table 6 various optical methods discussed in the sections above, are compared. However, some of the criteria mentioned here will be in subsequent sections. Of special **importance appears to be the column "Effect on vergence".**

Optical method	**Near accommodation**	**Effect on vergence** (section 3.5)	**Near vision**	**Distant vision**	**Usage / overall vision**	**Potential effect on myopia**
Large reading distance	Reduced accommodation	Reduced near esophoria	Good	Good	Easy	**Highly positive** for everybody
Plus glasses		Reduced esophoria		Reduced / insufficient acuity	Myopes: for near work only	**Highly positive** primarily for prevention (section 3.2.2.3.11)
Glasses - full correction	Full accommodation	Increased esophoria		Good	Easy	**Negative** (section 3.2)
Glasses - permanent undercorrection	Reduced accommodation	Increased esophoria (but less than with full correction)		Insufficient acuity	Only for near work o.k.	**Negative** (section 3.2.2.3)
Glasses - undercorrection for near work				Good	Need two glasses	**Positive** (section 3.2.2.3)
Glasses - bifocal or progressive					Easy, if fitting is o.k.	
Hard contact lenses - full correction	Full accommodation	None		Good	Easy	**Positive** (section 3.26.1)
Hard contact lenses - permanent undercorrection	Reduced accommodation			Insufficient acuity	Only for near work o.k.	**Positive** (section 3.26.1), but also **negative** (section 3.3)
Hard contact lenses and plus glasses for near work		Reduced near esophoria		Good	Easy	**Highly positive** (sections 3.26.1, 3.2.2.3.11)

Table 6 Comparison of various optical methods

Notes:

- *The column "**Potential effect on myopia**" reflects my **personal overall assessment**, based on the referenced sections about accommodation and about vergence/phoria.*
- *-As discussed in detail in section 3.5, **myopia is closely associated with esophoria and a high AC/A ratio**, which both result in a too-much-inwards-adjustment of the optical axes of the eyes at near focus.*

3.2.2.3.13 Psychological Problems with Special Glassear Workes for Near Work

The described principle of undercorrection, or bifocal- and plus-glasses is very often hard to accept by people:

With fully correcting glasses there is immediately good vision for all distances (at least for young people with full range of accommodation), which gives the feeling that "**everything is o.k. from now on**", and if people don't worry about the future myopia is no longer an issue. And in general, **people don't want to recognize a problem until there is already some damage**.

Using undercorrection, bifocal- and plus-glasses people are **faced permanently with the issue of non-perfect vision**. This will be tolerated only, if people are concerned about the future, but many people are hardly willing to face problems in general, and still less to face problems which arise in the future.

Therefore, this therapy may meet with resistance.

In the best case, people who are at risk to become myopic will use plus glasses for extensive near work already before becoming myopic to **prevent myopia**. I guess, however that people will read my book (and everything else about myopia) only if the problem is already there (it's like with everything in life, "**damage makes you wise**" - a translation of the German proverb "Aus Schaden wird man klug").

On the other hand, people who are already myopic **may have the feeling that "now, being myopic anyway, it does not matter anyway."** This group, however, should be fully aware that high myopia is not just a lens-related optical problem, but that it can have **very serious consequences** for the general preservation of the eyesight, potentially leading to blindness (see section 1.7).

I

3.2.2.3.14 How to Break an Accommodation Spasm?

In section 3.2.1.7 accommodation spasm was already discussed in some detail.

Sometimes an accommodation spasm is said to be the cause for myopia and the progression of myopia. Therefore, any method to break this accommodation spasm should be very helpful.

Viikari described the “fogging” method as a tool to break an accommodation spasm by using strong plus lenses which prevent focusing at all, (e.g. + 3.0 d) especially during refraction[41] (see section 1.11 and section 1.11.2).

Bowan[318] described another method to relax a focusing spasm, called "toe curls":

"After 20 or 30 minutes of close work, look away from your work to something 20 feet away or more that has printing on it, like a clock, a poster, a sign outside the nearby window -- whatever target you have that has notable detail on it.

While staring at the details, numbers, or lettering, tighten your toes downward inside your shoes, then progress up your legs, through your torso, fists, arms and neck, tensing all your muscles intently for about five seconds and then quickly release them all at one time.

If the target clears, that means there was a spasm of focus that just relaxed. If it does not clear, then there was not! (Or, you may have done a wimpy, wimpy job -- you may want to do the exercise one more time to make sure.)

Or, for the facial (10^{th} cranial nerve) variation, use a deep stroking pressure massage on the brow, and down the nose and across the cheekbones for 20 seconds. It’s generally quite refreshing."

Note:
This reminds somehow of acupressure (see section 3.26.5).

In section 3.3.1 some research results are mentioned, where short intervals of relaxing the accommodation prohibited myopia or reduced the progression of myopia.

3.2.2.3.15 Get New Glasses?

Schaeffel noted[319]-that most of the myopic people have the experience that the prescription of new glasses is accompanied with an accelerated progression of myopia, for which, however there is no proof in studies yet. Up to 0,5 D undercorrection might be partly compensated by an increased contrast sensitivity, which might give the feeling of proper vision without really providing all the details of an image.

Note:
*Results of the refraction might change somehow from day to day, and might be depending of the activities right before the refraction (section 1.3.2.4: "Because of these experimental results, it was concluded by McCollim[26] that "with repeated periods of prolonged accommodation the lens would never have sufficient time to return completely to the unaccommodated state"). **In** case refraction is taken on "bad days" with a tendency of over-refraction the result will be progression of myopia.*

3.2.2.3.16 Summary of the Accommodation Based Therapies

A schematic overview of the accommodation-based therapies is shown in Figure 8.

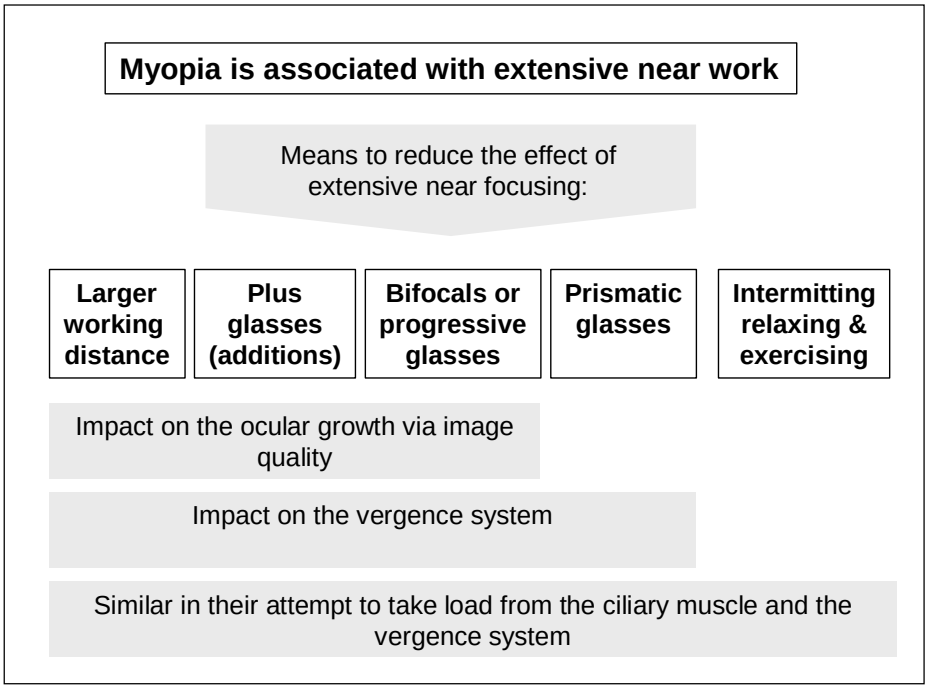

Myopia is associated with extensive near work
Means to reduce the effect of extensive near focusing:
Larger working distance
Plus glasses (additions)
Bifocals or progressive glasses
Prismatic glasses
Intermitting relaxing & exercising
Impact on the ocular growth via image quality
Impact on the vergence system
Similar in their attempt to take load from the ciliary muscle and the vergence system

Figure 8 The accommodation based therapies

In spite of the fact that the promoters of this method argue mainly from personal experiences only, scientific explanations for its potential efficiency exist[254] (see also sections 3.2.1 and 3.5).

Note:

*Even if some of the claims of the promoters of the accommodation-based therapies appear to be exaggerated ("reversing of myopia is **always** possible"), **there is no doubt that any reduction of accommodative stress (like large reading distance, plus lenses, bifocals, good illumination) is helpful and necessary to avoid the appearance of myopia and to stop the progression of myopia.***

*Nevertheless, **in any case, even with plus additions keep a proper distance for near work** to reduce the load from the oblique muscles, which are responsible for the vergence.*

Additionally, no negative side effects of these "therapies" were mentioned anywhere in the literature, therefore: try it!

Ip et al. supported the need to avoid excessive accommodation by their results when examining Australian school children[175]: "**Although myopia was not significantly associated with time spent in near work after adjustment for other factors, there were significant independent associations with close reading distance and continuous reading.** These associations may indicate **that the intensity rather than the total duration of near work is an important factor."**

In one paper, however, Schaeffel et al. stated[91]: "If variable genetic factors are major determinants of myopia in children, then modifying the visual experience (that is, doing near work with reading glasses), may not be very effective in inhibiting myopia development."

Note:
The logic of this statement appears to be questionable, as the following, controversial statement says: "... results indicate a high heritability for ocular refraction and its determiners and thus suggest that environmental impact on refraction is not significant. However, the epidemiological association between educational length (near work) and myopia, the evidence of increasing myopia prevalence within a few generations, and the theory of gene-environment interaction imply that ***some individuals might be genetically liable to develop myopia if exposed to certain environmental factors****."[101] Extra glasses for reading are creating a modification of these environmental factors, and therefore may be effective in protecting against myopia.*

In contrast to the statement above, Mutto DO summarized:[320] "**The ciliary muscle may play a greater role in emmetropization and myopia than previously thought. Time spent outdoors, not near work, may be the more important environmental variable in myopia. The effect of time outdoors shows an important interaction with a substantial genetic contribution to the risk of myopia**."

A less technical but more philosophical summary can be found in the Internet[321]: "**Human beings are highly adaptable organisms. The body will alter function to accommodate needs for which the system isn't able to compensate for. After enough use, the adaptation, if successful, may become part of the system for which it was meant to modify. Incipient nearsightedness brought on by focus problems is an adaptation our technological society is adopting."**

About **the positive effect of outdoor activities to counteract the negative effect of excessive accommodation** see section 3.8

Viikari emphasized, however[322]: "Once again: my main thesis regarding the prevention of myopia, is to start the prevention with plus glasses (in close work) beforehand, before there is any sight of minus and myopia at all!"

It is important to note, that the limit between "accommodation based effects" and "image quality based effects" is rather ambiguous as there are good arguments for both sides when interpreting specific results.

3.3 The Effects of Image Quality

3.3.1 Basic Results

Not too long ago (between 1977 and 1979) it was discovered that a lack of visual acuity on the retina leads to myopia in animals[97, 323].

This axial myopia can be artificially generated in animals by[117, 156, 324, 325]:

Covering the eyes of animals with **frosted glasses (form-deprivation myopia, FDM)**, or showing defocused pictures

Applying **strong minus glasses**[326] (**lens-compensation myopia,** called LCM, or **lens induced myopia, called LIM**; added plus glasses cause lens-compensation hyperopia, called LCH.)

Note:
This matches the results shown in section 3.2, where information about the correlation of permanent accommodation with myopia was given, and where it was warned of over-correction. Additionally it was reported before that near accommodation results in an immediate elongation of the eye.

Forcing the eye into **permanent near focus by restricting the distance of objects** that can be seen (this effect is illumination dependent).

Keeping the eyes in **permanent darkness**[327].

Keeping a developing **eye closed** by suturing an eyelid (not by keeping the animal in a dark environment).

Defects in the retina, which are caused by toxication[328] or malformation lead to myopia, and nystagmus, an instable trembling of the eye, leads to high-grade myopia as well.

Some findings and facts for this artificial myopia are:

At partly lens-covered eyes **only the respective part** of the sclera is changed[202, 329], i.e. the effect of the image quality is a local effect.

The **worse the acuity of the image** on the retina, the higher the myopia.

The feedback mechanism between bad focus / elongated eye is **taking place already in the retina**.

Applying **glasses works both ways**, i.e. applying plus glasses results in a shortening of the eye, resulting in hyperopia[330].

Feldkaemper et al. stated[331]: "… **the eye becomes more sensitive to image degradation at low light,** the human eye may also be more prone to develop myopia if the light levels are low during extended periods of near work."

A defocused image and especially a reduced **contrast** have not only an impact (extension) on the **vitreous body**, but also on the **length of the anterior chamber**[332]**.** In the early stage of myopia for children it was found, however that the vitreous chamber was already elongating, but the anterior chamber depth was still unchanged[333].

Note:
This implies that the impact of image degradation affects not only the area of the eye which is close to the retina, i.e. the back of the eye, but also the rather distant front part of the eye. Conclusion: The ***growth adjustment of the eye appears to be an almost systemic process****, which matches with some of the results given in section 3.3.2.*

Flickering light can stimulate the release of dopamine and reduce the degree of the artificially induced myopia[334, 335], and increase choroidal blood flow[2].

Eyes grow in length **only during the day**; at deprivation by translucent glasses they grow during night and day[47].

Ohngemach et al. stated[336]: "**Intermittent periods of normal vision** inhibited deprivation myopia more if they occurred in the **evening than in the morning**" and **relatively short periods (1 to 4 hours) were very efficient** to reduce or to prevent form deprivation[337].

Regular **interrupting the deprivation** can reduce the induced myopia, as Napper et al. stated[338]: "... several short periods of normal visual stimulation per day were more effective in preventing ... myopia ... than was one single period of the same total duration..."

Note:
These results give a scientific ***justification for the*** *experience driven recommendations of the* ***Bates-method*** *(see section 3.2.2.1).*

After artificially introduced myopia the eye **recovers to emmetropia** after the cover is removed from the eye. If the myopia is corrected with glasses, no recovering to emmetropia took place[339, 340].

Negative lenses, which cause myopic, elongated eyes, also cause a **thinning of the choroid** (the layer between the sclera and the retina). Vice versa, positive lenses, which are causing hyperopic, shortened eyes, also cause an also rapid increase in the thickness of the choroid[341, 342].

It takes **only a short time like 10 minutes for the eye to detect whether the added lens is a plus lens or a minus lens**, and to cause changes in the choroidal thickness and the corresponding vitreous chamber depth which **persisted still some hours later**[343].

Schaeffel summarized the status of the research about image quality[344]:

"**It is only the high spatial frequency content that is important** ... If high spatial frequencies in the retinal image are required to avoid myopia, even small amounts of defocus could be a major risk factor. ... It would not be advisable to under-correct myopic people, as this could stimulate deprivation myopia."

"**But this cannot be the whole story** ... There is another mechanism that determines whether the focal plane is in front or behind the photoreceptor layer ... **This mechanism provides a strong inhibitory signal for eye growth if the image is in front of the retina**, even though high spatial frequency components are lacking."

"The inhibitory signal is much more powerful ... four periods of only two minutes a day with positive lenses block deprivation myopia completely..."

Nickla[345] summarized the results of experiments with optical quality by saying that without appropriate and accurate optical stimulus the eye growth system going is into a "default" mode of excessive growth.

3.3.2 Connective Tissue Related Results

The results of deprivation and defocus as described so far sound like a normal and healthy growth of the eye, controlled by optical effects. The connective tissue of the modified sclera, however, is neither normal nor healthy (this is valid for the sclera of highly myopic humans as well)[346].

Rada summarized[360]: "Scleral remodeling, as with any tissue, is a dynamic process that involves continual synthesis and degradation of extracellular matrix." Numerous enzymes, proteinases and cytokines are involved in this process.

The following list is a summary of some of the most significant research results. They demonstrate that there is a very strong correlation between higher grades of myopia and defects of the connective tissue.

Scleral samples of artificially myopic tree shrew eyes (an animal frequently used for these experiments) were significantly **thinner and torn more easily**.[347] Similarly, highly myopic human eyes show scleral thinning at the posterior pole[346].

The **structure of the fibers** of the sclera was found to be different compared to normal eyes[348].

There is a **reduction of the amount of collagen and of the synthesis of proteoglycans**[349] [proteins, which are a main component of connective tissue besides collagen].

Any agent that is blocking the **cross linking of newly formed collagen dramatically increased myopia**[117].

Norton et al. stated[350] "… deprived sclera contained **less proteoglycan**, or that the proteoglycans were less glycosylated or less sulfated." This led to his conclusion, "...that form deprivation **slows or reverses the normal process of extracellular matrix accumulation** in the sclera of this mammal."

Rada et al. stated[351]: "The **turnover rate of … scleral proteoglycans** is vision dependent and is accelerated in the posterior sclera of chick eyes during the development of experimental myopia. The loss of proteoglycans from the scleral matrix involves proteolytic cleavage …"

Jones et al. stated[352]: "… eye growth induced by retinal-image degradation involves increases in the **activities of multiple scleral proteinases** [enzymes with the capability to dissolve proteins] that could modify the biomechanical properties of scleral structural components and contribute to tissue remodeling and growth."

Funata et al. stated[348]: "… a gradual increase in the **size of the collagen bundles and fibrils** from the inner to the outer layer of the sclera was observed in the control eyes, but was not evident in the myopic eyes."

Kusakari et al. stated[353]: "**Collagen fibrillar diameters** of the fibrous sclera in the posterior segment of myopic eyes were smaller than in control..." and "...**collagen bundles** of the fibrous sclera [of myopic eyes] spread into the cartilaginous sclera, whereas in control eyes the distinction was clear."

McBrien stated[339]: "… deprivation, which induced approximately 6 D of myopia, was accompanied by a three-fold **increase in the active form of gelatinase A** … an enzyme involved in collagen degradation." Rada et al. stated[354]: "... visual deprivation is associated with an increased amount of the 72-kd progelatinase and a decreased amount of TIMP [tissue inhibitors of metalloproteinases] within the posterior sclera." This means, there is an **imbalance between tissue degrading agents and agents, which stop tissue degrading** towards tissue degrading.

McBrien[355] also found **unaltered collagen fibrils after induced myopia of short duration. It was only when the animals remained myopic for many month that altered collagen fibrils were found."**

Furthermore, McBrien hade made clear that **not only mechanical effects are responsible for the stretching of the sclera[356]: "Analysis of the dry tissue weight of the sclera has demon-**

strated that the cause of scleral thinning in myopia is due to actual loss of scleral tissue as opposed to simply passive stretch of the sclera."

Note:
Even mechanical stretching alone, however, would result in a thinning of the sclera with a corresponding loss of tissue density.

Overall, McBrien outlined this sequence for the development of ocular elongation and high myopia[356]:

Signal from retina / choroid
↓
Decreased tissue growth factor TGF-β
↓
Decreased collagen synthesis
↓
Increased activity of metalloproteinase, an collagen degrading enzyme
↓
Tissue loss
↓
Ocular elongation

Rada summarized[360]: "… an **imbalance** between the levels of 72-kd progelatinase and its inhibitor may play a role in the remodeling processes of the posterior sclera during the development of form-deprivation myopia."

It was suggested by Siegwart et al.[357] that the sclera in deprived eyes "... offered **less resistance to vitreous-driven expansion** of the eyes."

Form-deprivation resulted in the **building of hypertrophic cells** (chondrocytes), i.e. in the **enlargement of cells instead of the building of new additional cells**[358]. In other words, there is **no growth, but a stretching by a degradation of the quality of the tissue.**

Note:
*It appears plausible that these enlarged cells are showing a **reduced stability**, which would explain the stretching of the sclera in an extended myopic eyeball.*

Gentle et al. stated[359]: "**Collagen type I expression was reduced** in the sclera of myopic eyes, however, collagen III and V expression was unchanged relative to control..." "...reduced scleral collagen accumulation in myopic eyes results from **decreased collagen synthesis and accelerated collagen degradation**." Collagen type I builds the main type of collagen in the sclera[360].

Rada et a. stated[361]: " Changes in the steady state **levels of gelatinase A and TIMP-2 mRNA lead to changes in gelatinase activity within the fibrous sclera and mediate, at least in part, the process of visually regulated ocular growth and scleral remodeling**."

Norton summarized[362]: **"In the chick model** of induced myopia, the cartilage grows, causing the eye to elongate. **In the tree shrew (a small mammal closely related to primates)** there is no loss of fibroblast cells that has been documented, but there is a loss of extracellular matrix. The amount of collagen is reduced, there is a loss of hyaluronan, selected degradative enzymes increase (but not all MMPs) and some tissue inhibitors of the MMPs (TIMPs) change. The result is that **the biomechanical characteristics of the sclera change** - the "creep rate" increases. We think that the increased creep rate (probably due to the lamellae of the sclera more easily slipping across each other) **allows normal intraocular pressure to cause the eye to elongate**. **No one knows if the same is true in humans**."

After induced form-deprivation myopia the **electrolyte balance in the vitreous was disturbed**: potassium and phosphate decreased, while chloride concentration increased. It was hypothesized that this change is caused by a reduction in the metabolic activity of the retina.[363].

Mertz et al. stated[364]: "...visual conditions that cause increased rates of eye elongation (diffusers or negative lens wear) produce a sharp decrease in **all-trans-retinoic acid** synthesis [from retinol, i.e. vitamin A] to levels barely detectable ... visual conditions which result in decreased rates of ocular elongation (recovery from diffusers of positive lens wear) produce a four- to fivefold increase in the formation of all-trans-retinoic acid". Correspondingly, Morgan stated[99] "synthesis [of retinoid acid] is increased under conditions that suppress eye growth..."

Supplementation of retinoic acid appears not to be helpful, because McFadden found[365]: "... **retinal-retinoic-acid increased in myopic eyes with accelerated elongation and was lower in eyes with inhibited elongation.** Retinoic acid levels in the choroid/sclera combined mirrored these directional changes. **Feeding retinoic acid RA (25 mg/kg) repeatedly to guinea pigs, also resulted in rapid eye elongation** (up to 5 times normal)."

Note:

It was shown that retinoic acid administered in the dark mimics the effect of light for some proteins expressed in the eye[366]; this offers a link to the results about the level of illumination, which will be presented in section 3.14.1.

The feeding with 25 mg/kg retinoic acid, however, has no relevance to any normal supplementation, this dose is extremely high.

Chicken with sutured eyelids showed **apoptotic cells (apoptosis is a programmed cell death) in the retina**[367] (see also section 3.18.1).

The peptide **glucagon**, and the gene **ZENK** play a role in experimental myopia of chicks[99].

This remodeling is typical for the adjustment process during growth, when the normally growing eye is optimized for best image resolution. Myopia occurs only when this feedback mechanism is disturbed.

Summary:

Obviously, the remodeling, which is a normal process during emmetropization, has also rather **destructive and degrading features** This makes it easy to understand that if a feedback mechanism is out of tune, it will lead to myopia. Some people may develop malignant myopia through such a mechanism. In other words, the process leading to myopia is **not only a passive one**, which is determined by simple mechanical stretching of a healthy sclera, **but an active one** with significant biochemical alterations[346], which includes that a biochemically degraded sclera is mechanically stretched.

It is still an open question whether the degradation of the sclera is completely caused by biochemical effects only. In this view, the reduced mechanical stability of the sclera is simply the effect of a changed biochemistry. The alternative is that **mechanical forces initiate biochemical modifications (a process called mechanotransduction**), which lead to the degradation[346].

In other words, **the big open question is whether the biochemistry of eyes, which will become myopic later, is already disturbed before the onset of myopia.**

A real and detailed understanding of the causation of deprivation myopia or lens-induced myopia, is still missing. There are some arguments that the experiments with animals are not fully valid for humans[368].

3.3.3 Dopamine and Light Exposure – and General Effects of Dopamine

See also the related section 3.14.1, "Level of Illumination".

Some results about the impact of dopamine on the biochemistry of the eye are:

- Nebbioso et al. Stated: " An increase of the retinal levels of dopamine activates D1 and D2 dopaminergic receptors present throughout the retina, generating a signal that inhibits axial growth once the eye has reached emmetropization."[369]
- Norton T and Siegwart J stated: " We propose a model in which the ambient illuminance levels produce a continuum of effects on normal refractive development and the response to myopiagenic stimuli such that low light levels favor myopia development and ele-vated levels are protective. Among possible mechanisms, elevation of retinal dopamine activity seems the most likely."[370]

·Lan W et al. summarized experiments with chicks: " In line with previous studies, we found that retinal dopamine release (as reflected by vitreal DOPAC content) was severely re-duced during development of deprivation myopia."[371]

The **dopamine** receptor availability in the eye is in fact dependent on the sunshine exposure, which was demonstrated by Tsai et al[372].

Note:
Nowadays people spending more and more time to work indoors and when being outdoors they seek the shadow because of fear of skin cancer and wear sunglasses – which is all in contrast to the environment to which our ancestors were adjusted by evolution.

Devadas et al. stated[373] that the level of dopamine is (among others) controlled by "a retinal dark-light switch … in the light-state it secretes **dopamine**, while in the dark state it secretes **melatonin** …". Dopamine and melatonin are blocking each other[375].

Flickering light can stimulate the release of **dopamine** and reduce the degree of the artificially induced myopia[334, 335] and increase choroidal blood flow[2].

A drop in the level of the neurotransmitter **dopamine** (released by specific retina cells) in the vitreous body accompanies experimental myopia, and agonists for dopamine (i.e. agents that are supporting the action of dopamine) can at least slow down this deprivation myopia[324, 374]. Correspondingly, dopamine antagonists (i.e. agents which are blocking the action of dopamine) can enforce myopia[375].

About **Amacrine cells** (types of neurons), Whikehart stated[376]: "...evidence indicates that amacrine cells (some of which use **dopamine**) serve as intermediate cells for the lateral transfer of signals across the retina", i.e. between the ganglion cells. Junqueira et al., however, stated[377]: "...their function is also obscure". Stone stated[378]: "... results ... suggest that dopaminergic amacrine cells may well be involved more generally in physiologic modifications of eye growth, not just in the form-deprivation myopia". This result, however, is disputed[379]. Colchicine, which destroys amacrine cells, promotes eye growth substantially[380].

MyCarthy et al.[381] reported "… suggesting that the protective effect of normal vision against form-deprivation is mediated through the stimulation of **dopamine** release and activation of D2-dopamine receptors."

Gao Q et al.[382] reported: "FD [form deprivation] by suturing eyelids is an effective technique to induce a significant myopic shift, vitreous chamber and axial elongation in rabbits as a model of myopia development. These changes associated with FD were retarded by intravitreal injections of DA [**dopamine**]."

Cohen Y et al. reported[383]: " The results showed that under light-dark cycles, **vitreal DOPAC concentration was strongly correlated with log illuminance, and was significantly correlated with**

the developing refraction, corneal radius of curvature, and axial length values. On day 90, low vitreal DOPAC concentrations were associated with myopia (-2.41 ± 1.23 D), flat cornea, deep anterior and vitreous chambers, and thin lens."

In experiments an effect of **dopamine** antagonists on the accommodation parameters "rate of accommodation" and "recovering from accommodation" were found[384].

Norton and Siegwart[385] proposed a model according to which the positive effect of time spent outdoors (see section 0) could be explained by the elevated illumination level outdoors and its activation of dopamineric pathways.

Backhouse et al. reported[386]: "In chicks, an increase in daily light exposure **continuously during the day is more effective at inhibiting myopia than adding an equivalent dose within a 2 h period of bright light**. A weak time-of-day effect also appears to be present in the response to bright light exposure. Our results suggest that future light-based myopia therapies in humans may be more effective if light levels are increased over the whole day, rather than through short periods of bright light exposure."

Dopamine **induces vasodilation, herewith improving blood circulation and smooth muscle contractility**[387, 388]. For the impact of blood circulation on myopia see section 3.17.

Notes:
Overall, however, it is suggested that the effect of dopamine takes place via a ***modified neurotransmission in the retina.***

Lan et al. reported[389]: "**Bright light stimulates choroidal thickening in chickens**, although the response is smaller than with experimentally imposed myopic defocus, and it occurs with some time delay. It nevertheless **suggests that choroidal thickening is also involved in myopia inhibition by bright light."**

In an overall review about dopamine and myopia, Zhou et al. stated[390] that dopamine release, which protects against myopia is not only depending on the intensity of light, **but also on image contrast**. Furthermore, not only dopamine itself can protect against the onset and the progression of myopia, **dopamine agonists**, too, can have a similar effect.

Schaeffel summarized[532] work by Tori and Wang: **Light of short wavelength might prevent myopia progression and increase the release of dopamine**.

It should be noted that a **n-3 polyunsaturated fatty acid deficient diet appears to have a negative impact on the level of dopamine**, see section 3.24.13.

See also the related section 3.14.1, "Level of Illumination" and and section 3.24.3. about the impact of the individual vitamin D status on the level of dopamine.

3.3.4 Remarks on the Image Quality Model

Some critical remarks against too simplifying conclusions drawn from image quality experiments are:

Most of the tests with experimental myopia were done with **chicks**; the chick, however, does not possess retinal blood supply[391], and also the sclera of chicks and mammals are very different[99]. For **monkeys**, at some species excessive accommodation is involved in experimental myopia, at other species it is not[391].

Moreover, Schaeffel et al. stated[91] that "there are also striking differences in the development of deprivation myopia in different populations of chickens." The result of experiments with mice was summarized by Schaeffel et al[392]: "Prolonged occlusion produces a **significant myopic shift in B6 mice, but not in D2 mice** [B6 and D2 are two different strains of mice]."

Note:
These results by Schaeffel underline the thesis that myopia is not caused by genetic heritage or by environment, but by the interworking of both (see section 3.30.7).

With all those experiments, myopia can be initiated to a predictable degree. People, however, don't react obviously not uniformly, i.e. when exposed to the same environment, the same tasks and the same nutrition, some people become myopic and some will not. In other words, **for people there are ways to counterbalance the impact of myopia initiating events**, which seem not to exist for the tested animals. The target of myopia prevention should be, to promote and enforce these counterbalancing mechanisms.

No explanation of the delay / lag of accommodation at myopes was given so far by the image quality model.

For a potential impact of the vergence issue on the results of experimental myopia see section 3.5.

These experiments can induce stress on the animals; stress, however, was found to be able to promote myopia as well (see section 3.19). Moreover, some of the experiments are increasing the temperature in the chick eye[393]; for the impact of the temperature on myopia see section 3.16. The stress model and the temperature model, however, cannot explain the different effects of positive and negative lenses (sign detection).

An anecdotal evidence of the image quality model: Somebody told me his myopia started in childhood when in school a reflection of the sun was hitting the eye from the side and this disturbance gave a disturbed image of the writings on the blackboard.

3.3.5 "Emmetropization" towards Myopia via Image Quality?

The title of this section sounds very controversial, as **emmetropia is in contrast to myopia** (see section 1.3.1). This issue is, however, more complex (see Figure 9):

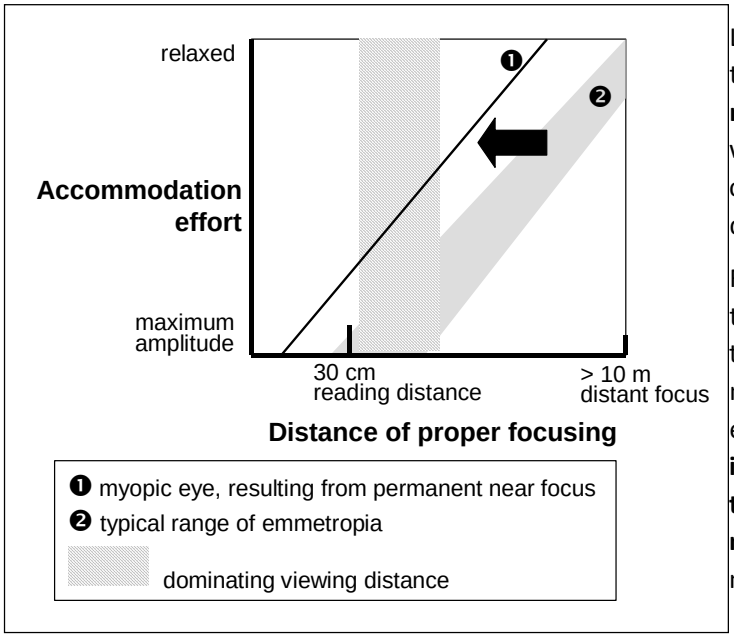


Figure 9 The shift of the accommodation effort caused by myopia

Literally the word emmetropization means that the **eye is going to the state of emmetropia** (see section 1.3.1), i.e. to a state where proper focusing of distant objects can be achieved with a relaxed accommodation.

Further the word emmetropization is used to describe the ability of the eye to adjust the eye-growth in length during development for optimal optical imaging. Wildsoet et al. stated[394]: "...when optical vergence **information is restricted to one plane, this plane becomes the end-point of emmetropization**." and "That eyes may emmetropize to distances other than real infinity is not a new observation ... laboratory-raised animals tend to be **more myopic ... when their environment is purposefully restricted**". In other words, emmetropization is used as well as the name of a mechanism, which **adjusts the eye length according to the preferred viewing distance**.

In the **history** of human development both definitions matched, because mostly the dominating viewing distance was the far distance.

Today, with often excessive near work, both definitions of emmetropia are controversial:

If the eye adjusts to the dominating viewing distance it will often become not emmetropic, but myopic! Therefore, "emmetropization" in this case does not lead to emmetropia, but to myopia!

Emmetropization in the sense of an adjustment of the length of the eye to achieve proper vision for "the individual, mostly used viewing distance" **is necessary when considering the individually different optical parameters of the eye before emmetropization takes place.** Emmetropization has to be seen as a very smart mechanism to balance for inborn optical differences and deficiencies.

There were **mathematical simulations of emmetropization and myopia** performed, taking into consideration interactions between **accommodation**, **vergence** and **optical blur**[395], and **level of illumination**[464]

(see sections 3.5.10, 3.14.1). **Astigmatism** appears to play a part in emmetropization as well (see section 3.5.6).

It is "agreement of the scientific world" that **emmetropization is driven by image quality signals on the retina only** [396].

The "more by practical experience driven world" however, argues, as well by "emmetropization towards myopia", **but by mechanical stretching** and recommends for near work the use of **undercorrection - or of plus lenses as prophylaxis for non-myopes to prevent myopia** - and its progression as discussed in section 3.2.2.3 and as summarized in section 3.15 (for the potentially negative effect of permanent undercorrection see section 3.2.2.3.6).

This process of "emmetropization towards myopia" explains well **why a steady prescription of glasses with higher power results very often in automatically increasing myopia.**

In a paper it was summarized that experiments with various animals (monkeys, tree shrews, guinea pigs, chicks) showed essentially the same: **added minus lenses resulted in myopia, added plus lenses resulted in hyperopia**[330].

The time of the interference with added lenses is important, as Metiapally and McBrien stated[330]: "Thus, not only the level of defocus is important in inducing appropriate compensatory responses but also the point in postnatal ocular development when defocus is initiated. This has important implications as to the timing of when any intervention treatments might be applied in studies to prevent myopia in adolescent children."

Notes:

- *In a way, for a situation of permanent near work the development of myopia can be interpreted as permanent and efficient "emmetropization", i.e.* ***not as a weakness, but as a very effective ability to adapt to a situation in the sense of evolutionary adaptation to the dominating distance of vision****. So, shortsightedness develops as an adaptive response to a situation where short focus is called for. The biggest handicap is, however, the resulting potential damage to the back of the eye, the sclera (see section 1.7).*

- *As emmetropization appears to work with a very different strength for various people, this process might be described by some kind of personal* ***"emmetropization factor", which is different for each individual*** *(apparently genetically determined) but which is also depending on personal habits like reading, illumination, accommodation response and last not least the individual biochemistry. Accordingly, myopia could be considered as an "****over-emmetropization****".*

- *A dangerous event is* ***the coincidence of "emmetropization towards myopia" according to the individual working/reading habits and a reduced strength of the connective tissue:*** *This leads with an elevated probability to an elevated "emmetropization factor", i.e. to higher degrees of myopia or to progressive myopia.*

- *As **many people don't become myopic** even when doing extensive near work, and without any plus glasses etc., the **individual biochemical differences must be very essential. In this case the individual biochemistry results in a reduced personal emmetropization factor.** The main tool, which is available to us to influence this biochemistry, is nutrition. In sections 3.18.3, 3.24 these biochemical issues are discussed in more detail.*

Besides the effect of "over-emmetropization" another potential reason for myopia is a **malfunction of the sign detection mechanism, and strong evidence for this was reported**[301], i.e. the problem would be not too much emmetropization, but **emmetropization in the wrong direction**.

Notes:

- *Even in this case, the resulting recommendation is undercorrection for near work (not permanent undercorrection!).*
- *Even if the published conclusion (that the problem is a malfunction of the sign detection mechanism) is true, this does not lead to a solution so far: The mechanism of the sign detection is not known yet[97], and therefore no tool to interfere here is available.*

Experiments with animals showed that emmetropization can even lead to a **recovery from a previously induced myopia when unrestricted vision is restored**[397], as long as the animals were young. Correspondingly, **fitting lenses with zero power in front of myopic eyes led to a recovery from myopia, whereas the application of corrective glasses (like the fitting glasses which is usually done!) prevented the recovery from myopia**[254].

While obviously near work creates signals for an increased axial length, **an inappropriate elongation might be avoided by corresponding "stop" signals**, as Morgan at al. expressed[398]: "Recent studies on natural STOP growth signals suggest that they are evoked by relatively brief periods of imposed myopic defocus, and can overcome strong pressures towards increased axial elongation. While stop signals have only been successfully used in chickens to prevent excessive axial elongation, similar signals are generated in mammals and non-human primates."

Apparently, however, the **reduced image quality is not the only effect, which influences emmetropization.** Results of by Metiapally and McBrien showed[227]: "**Constant +4 D lens wear produced +6.9 D relative hyperopia**, while +6 and +9.5 D lens wear did not induce hyperopia. Lens-induced defocus changes in refractive state were significantly correlated with vitreous chamber depth changes."

In other words, plus lenses were working in the opposite direction as excessive accommodation or negative lenses, as long as their power did not exceed a certain threshold when respective signals are no longer generated because of a too poor image quality.

Note:
When transferring these results from experiments with animals to humans, it might be concluded, that a permanent undercorrection from very young age on is of benefit as long as it does not exceed a certain threshold.

In the model described above myopia is the **result of a "natural" process of emmetropization** towards myopia.

In contrast to this model, Viikari found[41] that myopia is in most cases a **result of an accommodation spasm, which is contrary to the model of myopia caused by image quality signals as the "official" science tells.**

Note:
Or can emmetropization be simply driven by mechanical stretching during accommodation as discussed in sction 3.2.1.14?

3.3.6 Intermittent, Short Term Wearing of Plus Glasses

Note:
Before this section was placed under the section "Accommodation and Near Work". As, however, the effect of the short-term use of plus lenses can not only be explained by the accommodative action of the ciliary muscle, it was now placed under the section dealing with image quality – obviously the effects of short term myopic defocus are caused by a process related to image quality..

These results were confirmed by the results of Norton[456] (see also section 3.4):

Tree shrews were fitted with a negative lens (- 5 D).
For 45 minutes only each day the tree shrews were forced to focus at a distance > 1 m, and during this time the negative lens was replaced by various other negative lenses, or a plano lens, or various plus lenses (+ 3, + 4, + 5, + 6, + 10 D).

Results:

a) A **negative replacement lens** resulted in severe myopia
b) A **plano lens replacement lens** resulted in no myopia and no axial elongation of the eye, i.e. "the plano lens effectively competed against the – 5 D lens".
c) A **positive replacement lens** (+ 3, + 4, + 5 D) resulted in about half of the cases in myopia, in the other half myopia was prevented. The + 6 D and the + 10 D lenses, however, were ineffective in blocking the myopia.

Conclusion:

Even the rather short time of 45 minutes for wearing plano lenses or plus lenses can be enough to compensate the negative effect of the strong negative lenses.

Similar results were reported by Schaeffel[97]:
Two minutes per hour of wearing plus lenses were enough to cause hyperopia, even when the rest of the days minus lenses were applied. Two minutes per hour were found to be the minimum interval to be effective.
and[344]
"**The inhibitory signal is much more powerful ... four periods of only two minutes a day with positive lenses block deprivation myopia completely**..."

And Zhu, Winawer and Wallman stated[399] that "Even when chicks wore negative lenses [- 6 D or -10 D] for the entire day **except for 8 minutes of wearing positive lenses**, the eyes compensated for the positive lenses, as though the negative lenses had not been worn. ... Brief periods of myopic **defocus imposed by positive lenses prevent myopia caused by daylong wearing of negative lenses.** .... **regular, brief interruptions of reading might have use as a prophylaxis against progression of myopia**."

Matching with these results, McBrien reported about experiments with tree shrews[400]:

Continuous wear of -9.5 D lenses binocularly induced a **-10.8 D myopic shift** in refraction. Full-time wear of -9.5 D lenses binocularly, interrupted by 1 hour of **0-power lens** wear binocularly, caused a **myopic shift of 3.6 D** over 12 days, whereas wearing -9.5 D lenses, interrupted by 1 hour every day of +4.0 D lens wear binocularly, whether it was continuous or divided into two 30-minute periods, caused a **myopic shift of only 0.7 D** over 12 days. Conclusions: **Daily intermittent +4 D positive lens wear effectively inhibits experimentally induced myopia and may prove a viable approach for preventing myopia progression in children.**

By the way, it was told that the use of plus glasses is popular among pilots, for which perfect far-vision is essential[401].

3.3.7 Duration of Undercorrection

There is hardly any discussion about the duration of the different undercorrected or fully corrected states:

a) A person might do near work 90 % of the time, using undercorrection matching to this near work. Therefore, the remaining 10 % of the time a maybe harmful degraded image quality might appear.

b) A person might do near work 10 % of the time only, using undercorrection matching to this near work. Therefore, 90 % of the remaining time maybe harmful because of degraded image quality.

c) A person might do near work 90 % of the time, using full correction, which is not matching to this near work. Therefore, 90 % of the time a maybe harmful accommodation will exist.

These examples are showing **that a more specific condideration of an appropriate correction** appears to be useful.

3.3.8 Contrast and Spatial Frequency

With respect to the impact of the image contrast on the onset of myopia it was found:

Moore et al. summarized their results[402]: "**Reducing light levels effectively reduces the contrast of the visual environment. Reducing contrast has been found to produce myopia**, and our results agree."

Schmid KL et al. came to different conclusions, however[403]: "Our data do not support the suggestion that common reductions in letter size or contrast of reading material (as might occur for photocopied reading materials) cause greater accommodation inaccuracy and greater near work-induced adaptation effects that would exacerbate myopia development in young adults."

In a newer report the same author Schmid KL, however, reported results that are more detailed[404]: "**Emmetropia is maintained in the majority of animals at 47.5% contrast and higher. High levels of myopia occur in the majority of animals at contrasts lower than 4.2%.**" He further summarized: "An unanswered question that remains is **whether contrast itself provides the signal for emmetropization ... or whether the prevailing contrast level modulates the retina's ability to detect the key visual signal for emmetropization**."

Conclusion: Take care to have a good image contrast. The elevation of the level of illumination can help to achieve this (see section 3.14.1 about the level of illumination).

On the other hand myopia can be the cause of a reduced contrast, maybe herewith causing a progression of myopia: It was found that contrast sensitivity is reduced for myopes with more than – 6.25 D. Contact lenses were able to improve clearly the contrast sensitivity in these cases.

Some authors attribute the loss of contrast sensitivity for severe myopia higher than – 12 D to retinal function disturbances[405] and not to mere optical imaging effects.

Stoimenova found about contrast[406]: "Despite having corrected visual acuity, myopes exhibited reduced sensitivity to contrast in comparison to emmetropes. Furthermore, the contrast sensitivity decreased with an increasing degree of myopia, and the rate of decline was higher for negative than for positive contrast." See also section 3.3 about image quality.

Note:
This reduced contrast sensitivity, i.e. reduced image quality of myopes may create a negative feedback loop, causing myopes to become still more myopic.

3.3.9 Monochromatic Aberrations and other Optical Deficiencies

A spherical aberration is defined as a situation when a convex lens fails to focus parallel rays to a single point. This is due to deviations in the lens system. The spherical aberration of the eye is caused by the fact that the lens surface is not exactly spherical, but flattened at the periphery.

These aberrations can have a negative impact by the reduced image quality as described in section 3.3.1 and can therefore cause or at least contribute to the onset or progression of myopia.

Consequently, conditions, which cause this optical periphery to play a bigger part, will increase the amount of aberrations: **Stress** can widen the opening of the iris (see section 3.19.1) as well as a **low level of illumination** (see section 3.14.1).

Obviously the mechanism of emmetropization works extremely exactly[97], as Artal et al. stated[407]: "In most of the younger subjects, total ocular aberrations are lower than corneal aberrations...", i.e. the **emmetropization works, not only for the complete eye, but also for local imaging areas within the eye**. For older persons these results were not valid, which could explain the fact that myopia is progressing fastest in young age, and comes often to a stop later.

It can be concluded from these results that **myopia is never completely caused by mechanical forces only** – optical imaging and biochemistry has to play an important part. On the other hand it was found by Wildsoet et al.[394] that "accommodation plays an important role in deciphering distance information in the visual environment during emmetropization".

Some reports with respect to aberrations and similar optical deficiencies are:

Aberration is called **positive** if the "minority rays" are focused in front of the rays, which are passing the spherical part of the lens, and is called **negative** if they are focused behind them.

The **sign of spherical aberration was found to change by accommodation**, but there are results that it changes towards negativity[408] and there are results that it depends on the observer[409].

Rigid contact lenses, which have a positive effect on the progression of myopia (see sections 3.26.1 and 4.2), reduce the amount of positive spherical aberration, which results in a better optical quality than the one achieved by soft contact lenses or spectacle lenses[410,411].

Carney et al. stated[412]: "A tendency for the **cornea to flatten less rapidly in the periphery with increasing myopia** was shown."

Choo and Holden summarized[413]: "Recent work has suggested that **relative peripheral hyperopic defocus can also cause myopia to progress**, even in the absence of central vision. This opens up new possibilities for optical intervention to slow the progression of myopia."

Nio et al. stated[414]: "Both **spherical and irregular aberrations increased the depth of focus**, but decreased the modulation transfer [i.e. the image quality and the image contrast] at high spatial frequencies [i.e. fine image patterns] at optimum focus."

Spherical **aberration increases with increasing dilation of pupils**, and optical quality decreases as myopia increases[415].

Spectacle correction gives an exact optical image only for light, which is passing the lens in the center of it. It was reported[416] that deviations from this perfect image caused by light passing in the periphery of the lens induce peripheral hyperopia or peripheral myopia. Therefore, **different optical corrections, e.g. glasses of different design (e.g. aspherical design), different size and the choice glasses versa contact lenses might have an impact on emmetropization**.

Tabernero J et al. reported[417]: "It was found that the **peripheral retinal shape is more irregular even in only moderately myopic eyes**, perhaps because the scleral stiffness is affected already at an early stage of myopia development."

In contrast, Mathur A et al. found[418] that "… **aberration differed only modestly between the two groups [myopes and emmetropes]**, implying that it is unlikely that high levels of aberration contribute to myopia development.

Chinese Myopic eyes show a hyperopic shift in the periphery, hyperopic eyes show a myopic shift in the periphery.[419]

For children between 6 and 12 years it was shown that spectacle lenses, which were designed to reduce peripheral defocus, could reduce the progression of myopia. For older children this effect could not be observed[420].

Tarrant J and Wildsoet CF concluded[421]: "**Aberrations could explain the differences in accommodative responses between emmetropes and myopes**."

Gamba et al. reported[422]: "… study demonstrates that the **presence of larger amounts of high order aberrations produces an increase in accommodative lag**. This result could suggest that the increased accommodative amount found in myopes may be associated with the larger amount of high order aberrations in myopes."

Note:
As the accommodative process is playing a major part in the onset of myopia it is essential to keep these aberrations very low, e.g. by using bright light which reduces the aperture of the iris and increases the depth of field.

First trials to reduce the progression of myopia by reducing the peripheral errors of glasses[423] and contact lenses[424] gave positive results.

Accommodation delivers signals to cause eye growth. This can be concluded from the facts that the local shaping of the eye is triggered even by local aberrations (could be called "**micro-emmetropization**"), and as the process of accommodation causes immediate spherical aberrations. There are conflicting results whether accommodation causes positive or negative aberration. The question is: **Does the sign and the magnitude of the accommodation-caused-aberration determine whether people become myopic?** This question matches with the suspicion which was expressed in one paper by Chung et al.[301]: **"...strong evidence that myopia is caused by a malfunction of the sign detection mechanism in emmetropization..."** However, Carkeet et al. stated[425] "...results do **not provide any evidence for aberration-driven form-deprivation as a major mechanism of myopia** development." Additionally Cheng et al. stated[426] "...spherical aberrations [at myopes] was not significantly different from emmetropic eyes."

In contrast to the results of Cheng, Buehren et al. found that **myopes showed more aberrations than emmetropes, and these differences were increased after 2 hours of reading**. They concluded[427]: "The differences between the groups are primarily due to changes in the corneal wavefront associated with a narrower lid aperture during reading for the myopes. These differences are enhanced by longer periods spent reading, larger pupils and consequently low light levels. We suggest lid induced corneal changes caused by reading in downgaze provides a theoretical framework that could explain the known features of myopia development [by reduced retinal image quality]. **The inherited characteristics of facial and lid anatomy would provide a mechanism for a genetic component in the genesis of myopia."**

Note:
These lid-induced aberrations would explain at least partly the high rate of myopia among Asians.

Matching with these results, Collins et al. reported[428]: "**The myopic group showed significant reductions in various aspects of retinal image quality compared with the emmetropes**... The interaction between low and high order aberrations of the eye play a significant role in reducing the retinal image quality of myopic eyes compared with emmetropes."

If aberrations play a role in the development of myopia, there is be another strong argument in favor of bright illumination, because this results in a small aperture of the iris, and less aberrations (for information about the impact of the level of illumination see section 3.14.1).

A fashion to wear very small glasses results in principle in substantial aberrations, as the correct image created by the glasses is superimposed by a blur image of the rays, which are passing alongside the glasses.

About general optical deficiencies in the human lens system it was stated[429]: "Scientists believe that people become progressively more myopic because spectacles and conventional contact lenses cannot focus the eye sufficiently to stop it straining. The resulting eye growth causes further deterioration of sight." To overcome this problem, **individual** contact lenses will be fitted for a test with 400 people[429].

Note:
On one hand, this treatment might be successful by solving the reduced-image-quality-problem; on the other hand, there will be still the problem of excessive accommodation remaining.

McBrien, Morgan and Mutti[547]summarized presentations from the 12th International Myopia Conference: " Studies presented on the role of ocular aberrations at the conference increasingly indicate that **they do not play any particular role in the etiology of myopia.** In fact, they are more likely a consequence to the development of myopia."
Figure 11 in section 3.3.11 explains the reason for peripheral defocus.

3.3.10 Longitudinal Chromatic Aberrrations / Myopic and Hyperopic Defocus

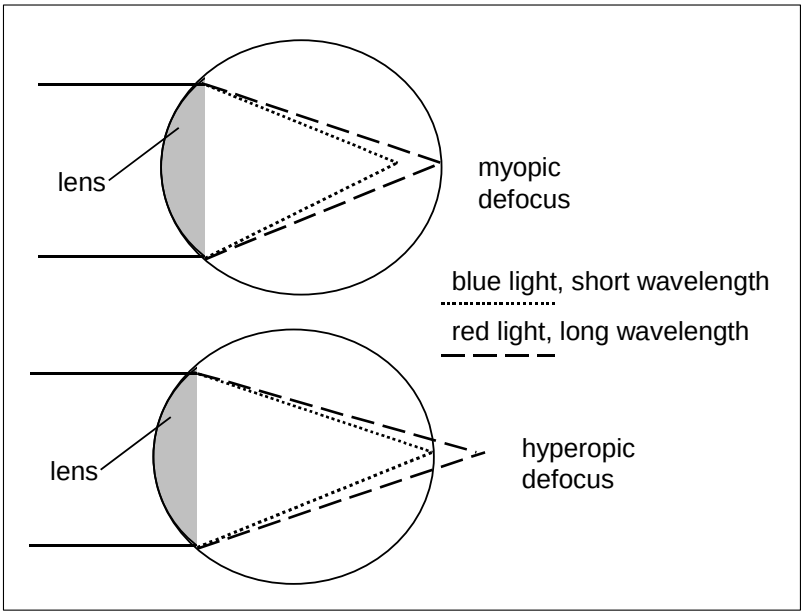


Figure 10 Myopic and hyperopic defocus / longitudinal chromatic aberration

See section 3.14.2 about specific effects of the color of illumination.

3.3.11 Peripheral Defocus and Dual-Focus Lenses

In section 3.2.2.3 there were bifocal glasses mentioned already; the effect of these bifocals is that the eye is either viewing and focusing through the upper "long distance part" or through the lower (plus-addition) "short distance part" to reduce the accommodative load when doing near work.

Smithe EL et al. found[430], that even when by a hole in a negative lens a sharp image in the fovea in the center of the retina was generated, the peripheral defocus of the negative lens resulted in myopia.

Berntsen DA et al. found[431]: "The adjusted one-year change in central SE [spherical equivalent] myopia was **-0.38 D for children with absolute superior myopic defocus** … and -**0.65 D for children with absolute superior hyperopic defocus**", i.e. superior myopic defocus helps to slow myopia progression.

Definitions:[432]

Hyperopic defocus: State of the eye in which the **retinal image is focused behind the retina**. It may occur **when placing a negative lens in front of an emmetropic presbyopic eye**.

Myopic defocus: State of the eye in which the **retinal image is focused in front of the retina**. It may occur **when placing a positive lens in front of an emmetropic** eye.

Correspondingly, Schaeffel summarized that **it appears that the accommodation is mainly controlled by the image at the fovea (i.e. the spot in the center of the eye, here is the best image quality), but the emmetropization is controlled mainly by the image quality at the peripheral retina**[53].

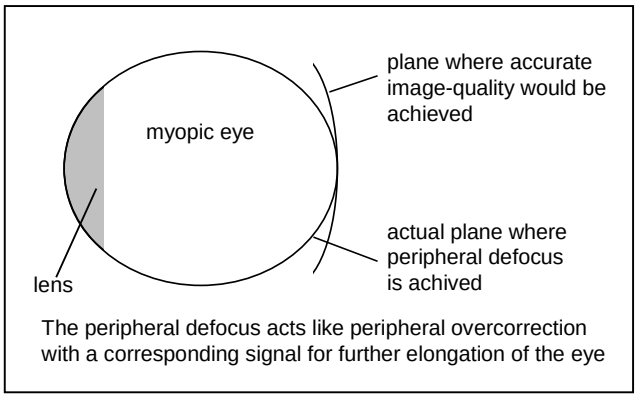

plane where accurate image-quality would be achieved
myopic eye
actual plane where peripheral defocus is achived
lens
The peripheral defocus acts like peripheral overcorrection with a corresponding signal for further elongation of the eye

Figure 11 The peripheral defocus

Figure 11 shows that for glasses with perfect central vision there is a peripheral defocus which acts as overcorrection and makes a further progression of myopia rather likely.

The more stretched, i.e. the more myopic the eye is already, the smaller is the radius at the back of the eye, and the larger is the peripheral defocus.

The consequence is that the higher the myopia is, the more pronounced is the negative effect of this peripheral defocus, and the harder it is to stop the progression of myopia.

New optical designs for spectacle lenses and contact lenses are aiming at eliminating this effect by introducing a "peripherally myopic defocus" where the peripheral image plane is adjusted to the actual shape of the cornea by adding a peripheral plus addition.

Note:
Maybe the negative effect of the peripheral defocus is larger for near accommodation than for far accommodation; if this is the case, excessive near work can be responsible for myopia by another effect than accommodation. It depends actually on the exact optical properties and performance of the lens of the eye and the shape of the retina at various viewing distances. No wonder bright light has a positive effect on myopia (see section 3.14.1), as optical deficiencies are less effective in this case.

On the other hand, there is a positive correlation between the amount of dark focus accommodation and myopia, see section 1.4.1. This can support either

- the hypothesis of myopia development and progression **by accommodative tension**, or
- the hypothesis of myopia development **by peripheral defocus**, as a permanently stressed lens might result in a degraded optical quality of the lens.

Overall, undercorrection might not solve this problem of peripheral defocus, as in this case there is a reduced image quality for distant vision in the center of the image plane.

To solve this problem results are reported where the glasses or lenses have a dual focus, which is resulting in permanent dual images at the retina:

Anstice NS and Philips JR reported[433]: "**Dual-Focus [soft contact] lenses** had a central zone that corrected refractive error and concentric treatment zones that created 2.00 D of simultaneous myopic retinal defocus during distance and near viewing." and "In period 1 [in the first 10 months] … in 70% of the children, myopia progression was reduced by 30% or more in the eye wearing the DF [dual focus] lens relative to that wearing the SVD [single vision distance] lens. Similar reductions in myopia progression and axial eye elongation were also observed with DF lens wear during period 2 [another 10 months]."

Hiraoka T et al. summarized results of various studies: Soft contact lenses with a central zone for correcting refractive errors and a peripheral zone with increasing positive power of up to + 2.0 D gave a reduction of between 33 % and 49 % of the progression on myopia compared with the use of single vision spectacles or single vision lenses for the first year.

The same principle appears to be used by the **MyoVision** spectacle glasses marketed by the company Zeiss in Asia and which are based on studies by Holden B et al.The arguments given by Zeiss are[434]:

For a corrected myopic eye with a flat-form lens, the image is projected on the retina centrally, but behind the retina peripherally due to the curvature of the retina. This means that for the periphery of the retina the glasses are overcorrecting. Therefore, "MyoVision corrects for central vision, but also moves the peripheral image onto, or in front of the retina. This has an effect of sending a "stop" signal to the eye to manage eye elongation."

Similarily as in the trial with soft contact lenses mentioned above, the trials with MyoVision glasses resulted in a reduction of myopia progression by an average of 30%.

H Kanda, however, reported[435] that the positive effect of MyoVision glasses could not be confirmed.

One one hand, one publication, however, could not confirm the positive effect of a new lens design to reduce relative peripheral hyperopia[436], on the other hand a more recent publication of the same author found myopia progression reductions by 33% and 34% by similar lens designs[437].

Schaeffel mentioned another new lens design[532]: "… there was a **multifocal spectacle lens** presented by Carly Lam et al.Glasses[438] from Hong Kong (the MSMD lens 'multifocal segment lens'). A 2-year randomized study in Hong Kong schoolchildren showed very **convincing inhibition of myopia (0.1 D progression with the MSMD lenses, vs 0.4 D progression per year in the controls, and no progression at all in 21% of the children, with 59% reduced progression on average,** …. Lam et al. also showed that there was **no effect on visual acuity at any luminance level** tested."

Glasses with this new lens-design are marketed by Hoya under the name MiyoSmart.[439]

Results by Liu Y and Wildsoet C[440] about two-zone bifocal spectacle lenses applied to chicks confirmed a positive effect of this type of glasses, which are based on a **peripheral defocus**.

Berntsen et al.[441] compared the myopic progression when wearing **progressive addition lenses** (PALs) and single vision lenses (SVLs). The change in myopia after 1 year was – 0.38 D for PALs and – 0.65 D for SVLs.

Backhouse et al. reported[442]: " Correcting the on-axis refractive error in moderate to high myopia with conventional spherical spectacle lenses results in hyperopic defocus in the peripheral retina. Correcting the same eyes with conventional spherical soft contact lenses results in significant myopic defocus in the peripheral retina. … If the refractive status of the peripheral retina does influence myopia progression, then these results suggest that myopia progression should be slower with conventional contact lens wear than with conventional spectacle wear. However, previous studies comparing myopia progression with conventional spectacles and conventional contact lenses have reported no such difference."

This **peripheral defocus occurs as well with contact lenses** as Kang et al. reported[443]: " Under-, full, and over-correction of central refractive error with single vision SCLs [soft contact lenses] caused a hyperopic shift in both central and peripheral refraction at all positions in the horizontal meridian. All levels of SCL correction caused the peripheral retina, which initially experienced absolute myopic defocus at baseline with no correction, to experience absolute hyperopic defocus. This peripheral hyperopia may be a possible cause of myopia progression reported with different types and levels of myopia correction."

Smith et al.[444] summarized their results and the results of various other authors about the impact of peripheral defocus very clearly: " results are in agreement with the hypothesis that **peripheral vision can influence eye shape and potentially central refractive error in a manner that is independent of central visual experience**."

Bullimore summarized[995] that a **change of peripheral defocus is responsible for the positive effect of orthokeratology on the prevention of myopia progression.** (See section 3.26.2)

Notes:

- *This peripheral defocus depends totally on the individual design of the individual contact lens or spectacle lens, and each manufacture has an own design, which interworks with very individual cornea and sclera optical properties in the peripheral region.*
- ***The peripheral hyperopic defocus is not just a problem of the lens design when correcting an existing myopia, but as well an issue before becoming myopic, because of the inborn geometry of the eye.***
- *This arises the question, whether rather small glasses (as used often for good looks and not for good vision) have a similar positive effect, as the light, which is not passing the glasses should create a myopic defocus as well. In case of stronger myopia, however, this "MyoVison"-Effect of very small glasses could be become negative and enhance the progression of myopia due to its blurring effect.*

3.3.11.1 Peripheral Defocus – New Applications for Spectacle Glasses and Contact Lenses

Some products are[445], and *L Ramon et al. published a general analysis of all the various concepts for bifocal and multifocal contact lenses*[446].

Peripheral defocus aspheric spectacle glasses: e.g. **Zeiss MyoVision and Essilor Myopilux**. The reported effect of these glasses was rather limited.

Multifocal **contact lenses**: e.g. **Cooper Vision MySight and Myopia Control DISC** (which is basis of a contact lens by **HOYA** as well). It was reported to **curb myopia progression in average by 59%**, to slow axial eye growth in average by 60%, and to halt myopia progression in 21.5% of Children. Basis of the design are concentric rings od various refractive power.

"**MyoSmart**" (also called Defocus Incorporated Multiple Segments, **DIMS**) by **HOYA** [439, 447, 448]: About **300 tiny plus-defocus elements** (+ 3.5 D) are inserted in the center of the **spectacle glasses**, with each defocus element of about 1 mm diameter.

Lam et al reported for these **DIMS spectacle glasses**[449]: "For subjects who completed the 2-year trial …, the mean myopia progression … over 2 years in the **DIMS** group (n=79) and the SV [single vision] group (n=81) was −0.38±0.06 D and −0.93±0.06 D, respectively. The total increase in AL was 0.21±0.02 mm and 0.53±0.03 mm, respectively. Schoolchildren wearing DIMS lenses had myopia progression significantly reduced by 59% (mean difference −0.55±0.09 D, p<0.0001) and **axial elongation decreased by 60% (mean difference 0.32±0.04 mm, p<0.0001) compared with those wear-**

ing SV lenses." Lam et al. claimed[450], "**Myopia control effect was sustained in the third year** in children who had used the DIMS spectacles in the previous 2 years and was also shown in the children switching from SV to **DIMS** lenses."

Bao et al. reported[451] reults with a similar design: "… treatment spectacle lenses have a spherical front surface with 11 concentric rings formed by contiguous aspherical lenslets (diameter of 1.1 mm). The area of the lens without lenslets provides distance correction. The geometry of aspherical lenslets has has been calculated to generate a VoMD [volume of myopic defocus] in front of the retina at any eccentricity, serving as a myopia control signal." Result: **For single vision lenses the mean change was − 0.81±0.06 D after 12 months, for the new design with highly aspheric design the change was reduced to − 0.27±0.06 D.**

3.3.12 Summary of the Effects of the Image Quality

Simplified the effects of the image quality can be summarized:

Image quality can control the dimension, the shape and especially the quality of the sclera.

The image quality has an impact on numerous biochemical processes.

It looks like that the reshaping of the sclera happens not via growth, i.e. cell multiplication, but via cell enlargement or stretching, and structural degradation (see section 3.9).

Aberrations appear to play a major part in accommodative process and the onset of myopia.

From the fact that continuous darkness causes myopia Norton et al. concluded[327]: "... continued visual guidance is necessary to maintain a match between the axial length and the focal plane or for recovery to occur. Absence of light is myopiagenic in tree shrews that have developed with normal diurnal lighting." In other words, **the development of myopia is here considered to be some kind of "default process" of the eye**, which is taking place even without the stimulus of an image.

On the other hand, there is a positive correlation between the amount of dark focus accommodation and myopia, see section 1.4.1. This can support either

- the hypothesis of myopia development and progression by accommodative tension, or
- the hypothesis of myopia development by peripheral defocus (see section 3.3.11), as a permanently stressed lens might result in a degraded optical quality of the lens.

The initiation and progression of myopia by the **image quality is still compatible with a genetic influence on myopia**:

Genetics may be responsible for the metabolism, and the power of the feedback process that control eye growth[452]. This is in addition to genetically caused weak basic connective tissue, which can be a reason for myopia as well.

From an engineering point of view, progressive myopia and lid suture myopia in primates showed the same open loop feedback process, i.e. there is no feedback in the process of progression involved[453].

Note:
In general, in publications about the impact of degraded image quality on the onset of myopia the negative role of near work and the corresponding advice for plus lenses is denied. However, the image quality based model can hardly explain why myopia is becoming tremenduously more widespread than before.

Additionally, there is some likelihood that a degraded image quality causes stress on the muscular system of the eye, which then causes the elongation of the eye by stretching.

3.4 Basic Question – what Elongates the Eye

In the section 3.2.1.14 "Emmetropization" towards Myopia via Accommodation? and section 3.3.5 "Emmetropization" towards Myopia via Image Quality? two respective models were outlined.

Some more results are reported in the following section.

3.4.1 Image Quality and Accommodation

The question to be asked is: **What is causing myopia, excess accommodation or a reduced image quality?**

The answer is, according to the experimental results, that there is a close interference between accommodation and image quality:

> Harb et al. stated[187]: "Within subjects, **accommodative lags significantly increased with closer reading distances**, however there was no significant relationship between lag and refractive state. The variability in the accommodative response significantly increased with closer reading distances ... Increased lags and the variability in accommodation at higher accommodative demands **suggest that an increase in overall blur at closer reading distances might be related to the development of refractive state**."

In similar experiments, it was found that generally **at a reading distance of 30 cm no perfectly focusing accommodation is performed**[188]. **The resulting degradation of the image quality can contribute to the development of myopia.**

Gwiazda et al. stated[196]: "Both types of **AC/A ratios are elevated in myopic children** ... Myopic children with esophoria underaccommodate at near. This suggests that a child who is esophoric must relax accommodation to reduce accommodative convergence and maintain binocular vision. **The reduction in accommodation could produce blur during near work, which could induce myopia as in animal models**".

Conclusion: There is no controversy between the observations of myopia caused by degraded image quality and the observations of myopia caused by excessive near work.

Note:
The research results indicate that both, excess accommodation and a reduced image quality can play a role in the onset of myopia. It might depend on the individual person whether one effect dominates.

It appears that **a blur image has a different effect for myopes and emmetropes**: Vera-Diaz summarized earlier results [454] "... myopic children show reduced accommodative responses to negative lens-induced blur...", and added new results[454]: "Compared to pre-adaptation level, myopes showed a significant increase in the near accommodative response after 3 min of blur adaptation, while accommodation to the near target in emmetropes did not change."

Note:
Open Question: Is this modified accommodation of myopes a result of their myopia, or are they myopic because of their modified accommodation? An answer would be helpful for fighting the onset and progression of myopia.

The effects of various environmental conditions were investigated and summarized by Yi JH and Li RR[455]: "The annual mean myopia progression (0.38 ± 0.15 D) in the intervention group was significantly lower than that in the control group (0.52 ± 0.19 D; P<0.01). The children in the two groups spent similar amounts of time in near-vision activities, but the children in the intervention group **spent less time in middle-vision activities** (P<0.01) and more outdoor activities (13.7 ± 2.4 vs 6.2 ± 1.6 hrs/wk; P<0.01). When considering all children in the study, **there were 4 factors that significantly correlated with less myopia progression: more outdoor activities, more time spent wearing glasses, more time spent in natural light and less time using a computer."**

An interworking is taking place between image quality and the level of illumination, as discussed in section 3.14.1

3.4.2 Myopia by Accommodation or Myopia by Degraded Image Quality?

It was described above that as well

- excessive accommodation as well as
- degraded image quality

were made responsible for the development of myopia.

As some followers of each of these two theories state that only one of these theories can be correct the following results published by Norton[456] appear to show **that it is not an "either or", but an "and":**

Tree shrews were fitted with a negative lens (- 5 D).

For 45 minutes each day the tree shrews were forced to focus at a distance > 1 m, and during this time the negative lens was replaced by various other negative lenses, or a plano lens, or various plus lenses.

Results:

a) **A negative replacement lens resulted in severe myopia**

b) **A plano lens replacement lens resulted in no myopia and no axial elongation of the eye**

c) **A positive replacement lens resulted in about half of the cases in myopia, in the other half myopia was prevented.**

Conclusion: Both theories are valid. **Excessive accommodation can cause myopia, and regular relaxation from myopia can prevent it.**

Excessive use of plus lenses, however, which results in a degraded image quality results often in the onset or the progression of myopia (result c)).

These results, which are reflecting the effect of the degraded image, are matching very well with the results presented in 3.2.2.3.6 (Permanent Undercorrection instead of Undercorrection for Near Work only).

Wu S et al. **made a point against the concept that myopia would be caused by reduced image quality only**[853]:
"Currently, it is confirmed that the development of myopia is associated with the disorders of accommodation. As a dominant factor for accommodation, ciliary muscle contraction/relaxation can regulate the physiological state of the lens and play a crucial role in the development of myopia. …

We found that the arrangements of ciliary muscles in LIM [lens induced myopia] guinea pigs were broken, dissolved or disorganized …. Monitoring of K [potassium] flux in ciliary muscles from LIM guinea pigs demonstrated myopia-triggered K influx. … Overall, our results will facilitate the understanding of the mechanism associated with inhibitory Na /K -ATPase [adenosine triphosphate] in lens induced myopia and which consequently lead to the disorder of microenvironment within ciliary muscles from LIM guinea pigs, paving the way for a promising adjuvant approach in treating myopia in clinical practice."

Notes:

As it was already mentioned in section 3.2.1.3 that close near work and strong accommodation reduces the image quality a rather likely synthesis of as well the accommodation model as well the image quality model appears to be:

Short distance to near work or reading results in strong accommodation, which degrades the accuracy of accommodation (either by muscular effects or effects of neurotransmission) and herewith degrades the image quality – the result is myopia.

Moreover, it appears plausible that muscles, which are stressed by excessive load, might have a problem with fine-tuning (just thing of doing hard manual labour and then very fine manual adjustments – your hands won't be very sensible).

Moreover, every photographer knows that at near distances the focusing becomes more difficult and more inaccurate, which degrades image quality, which favors myopia.

A model, which matches some of the reported results, might be therefore:

Imperfect image quality, maybe caused by extensive accommodation
↓
Local degradation of the scleral tissue by biochemical processes
+ Muscular tension / intraocular pressure, e.g. by extensive accommodation
↓
Ocular elongation

An alternate model, which matches some of the reported results too, might be:

Excessive accommodation
↓
Local degradation of the ciliary muscle tissue
↓
Inadequate accommodation, accommodation lag
↓
Reduced image quality
↓
Ocular elongation

The resulting advice is:

- **Avoid short viewing distance and excessive accommodation,**
- **Take care of excellent illumination, best with a short wavelength, i.e. "cold" light to provide best image quality by high contrast**
- **Take care of regular relaxation,**
- **Avoid <u>permanent</u> plus correction or substantial undercorrection as it results in degraded image quality for the respective viewing distance (see *note* below).**

Note:
There is some likelihood that a degraded image quality causes stress on the muscular system of the eye, which then causes the elongation of the eye by stretching.

Obviously, it depends on the duration and the strength of accommodation, and the duration and extent of degraded image quality.
Therefore people who are most of the day doing near work with plus lenses or plus additions which still give them a perfect image should not be at great risk by the occasionally reduced image quality at distant vision with these plus glasses or plus additions. In this case, there would be no excessive accommodation, and only a short time of reduced image quality.

Actually, it does hardly matter whether myopia is caused by muscular accommodation or image quality processes: In both cases, there is agreement that excessive near work or near adaptation is responsible.

3.4.3 Emmetropization by Growth or Mechanical Stretching or Biochemical Thinning?

Numerous publications talk about "growth" of the eye in connection with emmetropization and myopia.

"Growth", however implies generally an extension by building new cells, in contrast to stretching where existing cells and structures are lengthened by mechanical force and subsequent thinning. Moreover, a biochemical degradation of scleral tissue was found to be responsible for the thinning of the sclera as well.

Myopia, expecially higher degrees of myopia are undoubtedly accompanied by thinning: "When ocular elongation accelerates during myopia development, the fibrous sclera thins in mammals[396] "

For emmetropization before the onset of myopia, however, there appears to be no information available whether the cause of the elongation is builtup of new cells (i.e. real growth) or stretching.

For more information about the question "growth or stretching" see section 3.9.

3.5 Phoria, Convergence, Astigmatism and Anisometropia

When focusing on near object three things are happening automatically:

Accommodation

Convergence, i.e. the adjustment of the optical axes more inward compared to distance focusing

Narrowing of the pupils.

3.5.1 Phoria

Phoria is a defect, in which this adjustment of the optical axes of both eyes to focus an object is not properly coordinated. This defect can be permanent, or it can be transient, e.g. under stress, nervousness, tiredness etc. **Rather pronounced misalignment of the axes is called strabismus**.

It can be that the axes of the two eyes are adjusted too much inwards when accommodating – **near esophoria** – or too much outwards – **exophoria**. Esophoria and exophoria are transient effects; if the maladjustment is permanent the corresponding effects are called **esotropia** and **exotropia**.

Some results are:

It was reported that **higher myopia rates are occurring especially with esophoria at near**[203, 457] Chung et al. stated[458]: "The results support the hypothesis that **near esophoria is associated with high myopia**". The higher the esophoria was, the higher was the myopia progression rate. This matches plausibly with the correlation between elevated AC/A ratios (see section 3.5.2) and myopia. An explanation is the optical blur (i.e. not-perfect imaging) caused by esophoria.

Brown et al. stated[280]: "In the progressive lens group, change toward **more exophoria at near was associated with less myopia progression**."

Esophoria at near was positively treated with added plus lenses, respective bifocals[275].

Moreover it Brown et al. reported[280] that "... there was **only 46% as much myopia progression in the progressive lenses-esophoric group as in the progressive lenses-non-esophoric group**." This means that progressive lenses (see section 3.2.2.3) were especially effective for myopes with esophoria.

Additionally, a practitioner wrote that in his praxis pseudo-myopia, i.e. a **spasm of the accommodation was frequently accompanied by esophoria**[7].

Note:
Can it be that this elevated inwards convergence at near initiates an over-accommodation via the CA/C ratio (see section 3.5.3)?

Mutti et al. stated[459]: "There is no association [between myopia and esophoria] when phoria is evaluated while children wear their current, habitual corrections. Yet many studies report a high prevalence of esophoria among children with myopia wearing a **new, rather than a habitual correction."**

Note:
This could be explained by the AC/A ratio (see section 3.5.2). A new and increased correction implies a stronger accommodation at near, and a resulting increased convergence.

In phoria there is some misalignment of the muscles of the eye, especially the **oblique muscles**, and at the more established form of Phoria, **at strabismus, surgery for these muscles is performed**.

In section 3.7.3 it is described that a load on these muscles can elongate the eyeball, and create herewith temporary and in the long run permanent myopia.

Whether a near esophoria is preceding myopia, i.e. causing myopia, or just accompanying myopia is not absolutely clear.

Note:
Additionally it might be possible that esophoria and myopia are not causing each other, but are caused together by another biochemical or biomechanical process.

3.5.2 The AC/A Ratio

A related parameter is the "**AC/A ratio**", i.e. the ratio of **automatic inwards convergence of the axes of the eyes with respect to the accommodative effort**. In other words: The nearer an object is, and the higher the accommodative effort is, the more the visual axes of the eyes will be adjusted inwards, triggered by the accommodative effort. The AC/A ration describes the degree of inwards adjustment in relation to the accommodative effort. In esophoria the AC/A ration is too high.

Often AC/A ratios, and results based on **measured AC/A ratios are hardly comparable**, because they are based on different definitions and different techniques for measuring[459, 196].

As it was mentioned in section 1.11 phoria can be easily misdiagnosed when children are in fact hyperopic[78].

Some results are:

Gwiazda et al. stated[196]: "Both types of **AC/A ratios are elevated in myopic children** ... Myopic children with esophoria underaccommodate at near. This suggests that a child who is esophoric must relax accommodation to reduce accommodative convergence and maintain binocular vision. The reduction in accommodation could produce blur during near work, which could induce myopia as in animal models".

In another publication by Gwiazda it is said[460]: "Compared with children who remained emmetropic, those who became myopic had **elevated response AC/A ratios at 1 and 2 years before the onset of myopia**, in addition to at onset and 1 year later. The significantly higher AC/A ratios in the children who became myopic are a result of **significantly reduced accommodation**. Accommodative convergence was significantly greater in myopes only at onset ... These findings suggest that the abnormal oculomotor factors found before the onset of myopia may contribute to myopigenesis by producing hyperopic retinal defocus when a child is engaged in near-viewing tasks."

The problem of under-accommodation of myopes was already mentioned in section 3.2.

Mutti et al. stated [459]that "... the response AC/A ratio was an important **risk factor for the onset of myopia** ... data suggest that the onset of myopia follows rather quickly, **within 1 year, if the AC/A ratio is high**.", i.e. it was not just accompanying myopia.

Lu et al. stated[461]: "Ocular motor parameters are different in myopia eyes. AC/A is one of key parameters among them, and AC/A is increased in myopia, which indicates out of focus of retinal image in the developing myopia... There was significant difference in phoria in near between the myopia group and emmetropia group, but none in that of distance."

A study by Chen et al.[462] with children in Hong Kong, however, could not confirm these results: "AC/A ratios appeared higher in progressing myopic children but the difference was **not statistically significant**."

Attention has to be paid to the AC/A ratio when fitting **bifocal glasses** to ease accommodation for near work (see section 3.2.2).

Notes:

- ***A high AC/A ratio corresponds in its effect to esophoria.***
- *The AC/A ration might depend on the distance of the object in a non-linear way. Possible consequence: For reading a distance might be chosen, where **convergence is adequate, but where extra accommodative effort is necessary**, because the distance is actually too near. This excessive accommodation effort (see section 3.2 about the impact of accommodation) alone could contribute to myopia – as well via the image effect thesis (see section 3.3) as well via the mechanical thesis (see section 3.7).*

The schematic relationship between accommodation and convergence is shown in Figure 12.

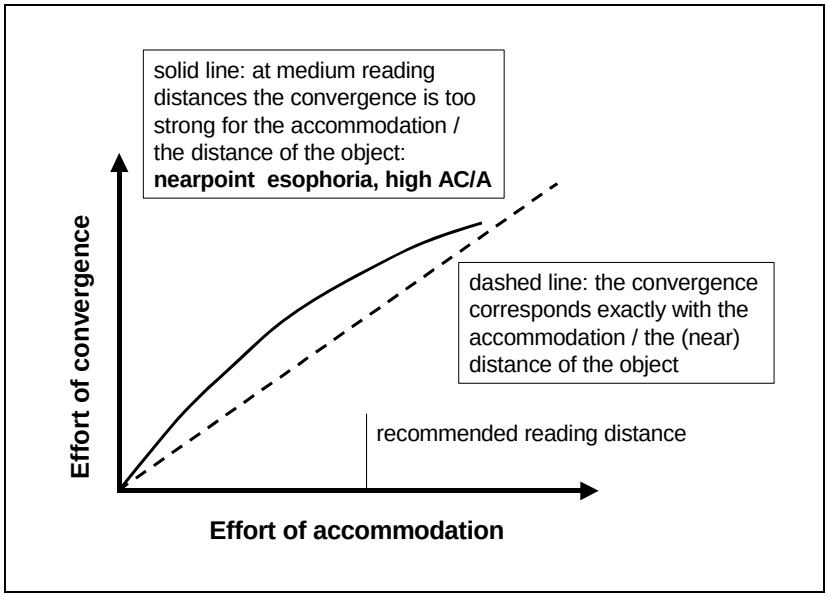

solid line: at medium reading distances the convergence is too strong for the accommodation / the distance of the object:
nearpoint esophoria, high AC/A
dashed line: the convergence corresponds exactly with the accommodation / the (near) distance of the object
recommended reading distance
Effort of convergence
Effort of accommodation

Figure 12 The relation between accommodation and convergence

Note:
It is not mentioned in the literature, but it appears to make sense:

If the AC/A ratio is too high, and proper convergence is achieved only at a distance that is shorter than the distance recommended for reading, the use of ***prismatic glasses, which compensate for the over-convergence at near distance*** *might be very useful. With glasses like this (****no undercorrection as mentioned in section 3.2.2.3****) a proper reading distance with normal accommodation could be achieved.*

3.5.3 The CA/C Ratio, and some more Types of Vergence

It is not only the case that accommodation initiates a certain amount of vergence (AC/A) as described in section 3.5.2. Vice versa **vergence triggers a certain amount of accommodation** ("convergence accommodation")[463]. This fact is described by the convergence accommodation/convergence (**CA/C**) ratio.

It was stated by Blackie et al.[464] that "...**a low CA/C ratio exacerbate the progression of near-work induced myopia**".

In section 1.4.1 the dark focus of accommodation, or tonic accommodation was mentioned. A corresponding effect for vergence exists: the **tonic vergence** or **dark vergence**, which is the adjustment of the axes of the two eyes in the dark or when closed. These two effects (i.e. tonic accommodation and tonic vergence) respond differently to an increase in illumination. There is a large individual bandwidth, as Jiang et al. stated[465]: " The critical luminance level at which the two responses were coupled for the 12 observers ranged from 0.01 to 0.45 cd/m2, with distinct individual differences."

Disparity vergence or **fusional vergence** is the effort to match the images of an object on the retinas of both eyes by the adjustment of the two visual axes.

At a more permanent fixation to near points (e.g. while reading) the disparity vergence and the accommodative vergence are gradually replaced by **vergence adaptation**.

It was said that the AC/A ration rises with age, and that CA/C is falling with age (considered range of age 16 to 48 years)[466].

Notes:
- *Obviously the mechanisms of vergence are highly complex, and are closely related to accommodation. A* ***strategy to handle progressive myopia should therefore pay high attention on a well-balanced vergence*** *(see also section 3.2.2.3).*
- *It appears that in the results of* ***experimental myopia*** *(see section 3.3) little attention was paid to the vergence issue; it looks like models that consider convergence, could explain some of these results from a different point of view[464].*

- ***Reading in bed**, especially lying on the side might be rather critical: Besides the effect that it leads mostly to a too near reading distance, the reading distance can be different for the two eyes, with unknown consequences of accommodation, vergence, AC/A and CA/A ratios.*
- ***It can be concluded, that wearing plus glasses but still doing near work at very short distance has to be avoided, because of the convergence, which is caused by the short distance. Reason: this convergence can still have an impact on accommodation.***

3.5.4 Hysteresis of Vergence

In section 3.2.1.3 and section 3.2.1.5 hysteresis effects of accommodation were discussed. In fact, an analogue **hysteresis effect exists for the vergence**[467].

Note:

As a consequence, an impact on myopia could happen via this effect as well, either via the "reduced image quality model" (see section 3.3) or via the mechanical stress model (see sections 2.4 and 3.2).

3.5.5 Glasses, Contact Lenses and Vergence

Glasses have a **prismatic effect**, which is proportional to the degree of myopia and works towards nearpoint esophoria. This effect does not exist for contact lenses. For contact lenses, however, there is a higher degree of accommodation. As a consequence, Grosvenor et al. stated[468]: "If the AC/A ratio is moderate, the two effects tend to cancel each other out, but with a high AC/A ratio, the accommodative convergence effect may predominate, and with a low AC/A ratio, the lens centration effect [i.e. the not existing prismatic effect of contact lenses] may predominate."

The **claimed positive effects of plus lenses on myopia** (see section 3.2.2.3) can be at least partially based on this prismatic effect of the plus lenses, i.e. a **smaller exophoric** shift[274].

The data in Table 7 correspond well with the claim that **minus lenses tend to increase myopia**, whereas **positive lenses are said to decrease myopia** (see section 3.2.2.3), and the result that myopia is often associated with esophoria (see section 3.5.1).

Optical application	**Shift towards esophoria, reduction of exophoria** (associated with myopia, see section 3.5.1)	**Shift towards exophoria, reduction of esophoria**
Optical application	**Shift towards esophoria, reduction of exophoria** (associated with myopia, see section 3.5.1)	**Shift towards exophoria, reduction of esophoria**
Minus glasses	**X**[468]	---
Overcorrecting minus glasses	**X**[172]	---
Plus glasses	---	**X**[274, 275]
Plane (zero D) glasses	---	**X**[274]
Contact lenses	---	---
High AC/A ratio	**X**[469]	---

Table 7 The influence of optical devices on the convergence

3.5.6 Prescription of Prisms

When a plus lens without a prism is used for reading there is an impact on the balance between convergence and accommodation: accommodation is saying that the object is farther than without the glasses, but the vergence still considers it as near.

About the load of vergence on respective muscles of the eye and their impact on the elongation of the eye, i.e. the onset and progression of myopia see section 3.7.3.

Therefore, to give the brain the complete and matching information of an object which is farther away, the plus lens have to be combined with an appropriate prism[252].

The unit in which the power of a prism is given is called prism diopter, sometimes abbreviated △ or PD). One prism diopter corresponds to the deflection of light by 1 cm at a distance of 1 m. The prism effect can be "base in" (rays of light inwards) or "base out" (rays of light outwards).

Common prescriptions of the add-on prism of plus glasses for near work are between 0.5 PD and 2 PD (sometimes up to 4 PD), base in. Very common are just 0.75 PD.

Note:
The prescription of these prism add-ons can be based on two different reasons:

- *a simple compensation of the plus lenses to achieve a stress-free convergence*
- *a compensation of a convergence problem, which may exist already independent of the plus glasses for near work.*

As already mentioned in section 3.5.5, the plus lens has a prismatic effect even without a specific prism add-on. This prismatic effect depends also on the adjustment of the bridge measurement (distance between the lenses) with respect to the pupillary distance. A de-centration of the optical center of the plus glasses to the nasal side of the frame results already in some desired base in prism.

Note:
Consequently, those cheap off the shelf reading glasses can mostly be expected to have some prismatic effect, and this prismatic effect can be base in (desired) or base out (undesired). ***Therefore, better get custom made reading glasses.***

Properly fitted **plus lenses with prism are an essential part of vision therapy** (see section 3.15), as Bowan stated[252]: "Recently, another function of these lenses has become apparent in certain cortically hypersensitive Brains: **these Brains suffer from image aliasing**[309,310,311] **creating an illusion of movement and other oddities (mirages) because of the textual stripes**. The plus and/or prism eliminates the mirages and may affect Brain cognitive processes directly for poorly understood – but clinically easily observed – reasons."

Note:
Obviously, it needs a skilled optometrist to determine the data of appropriate plus glasses for near work. The off-the-shelf reading glasses from department stores are not matching these quality requirements.

There might be another strong reason for the prescription of prism lenses: Bayramlar reported[470]: "We observed axial-length elongation during near fixation both with and without cycloplegia. **Based upon this result, one can conclude that convergence, a component of near reflex, rather than accommodation, may cause axial-length elongation during near looking… Much use of convergence, not accommodation, may be one of the contributing factors in adult onset and adult progression of myopia."**

In this paper, the validity of these results was not strictly limited to adults, however; the experiment was performed with 15-year-old male persons.

Note:
This potential impact of vergence stress is another very strong reason to keep a sufficiently large distance for near work and reading.

3.5.7 The Impact of Vergence on the Axial Length

About the load of vergence on respective muscles of the eye and their impact on the elongation of the eye, i.e. the onset and progression of myopia see section 3.7.3.

3.5.8 Astigmatism

Another optical defect, **astigmatism**, was found before to have hardly an impact on myopia progression rates in two papers[471, 472].

More recently it was reported by Gwiazda et al.[473] that "... children with significant against-the rule astigmatism as infants are more myopic...", and the high prevalence of astigmatism and myopia at American Indians[474, 475] makes a correlation between astigmatism and myopia more likely.

In contrast to the results by Gwiazda, Czepita stated[476]: "With-the-rule astigmatism predisposes the creation of myopia. Against-the-rule as well as oblique astigmatism has no influence on the creation of myopia."

Schaeffel summarized that when the eye is determining the amount of appropriate accommodation astigmatism is ignored[53].

3.5.9 Anisometropia

It is called Anisometropia when the refraction of both eyes is significantly different from each other. Thre question is whether in this case the prescribed glasses should be different as well, and according to the results of the refraction.

Viikari recommends to use in this case the results of the refraction of the eye with less diopters[41].

3.5.10 Summary of the Vergence Related Effects

It appears plausible that an obvious disturbance of the **control circle: near focus – accommodation – convergence** can happen. These disturbances can lead to poorly focused, blurred images on the retina, which in turn can lead to myopia as shown above. A remedy, however, to prevent myopia or myopia progression by interfering with this convergence feedback circle, has not yet been established.

Together with the results of the influences on image quality, there are indications that there is a chain of processes for a development towards myopia[107, 196], which looks like Figure 13:

Bowan called this interaction between accommodation and convergences “**accommovergence**”, and therefore **recommended the use of plus additions combined with prisms**[477].

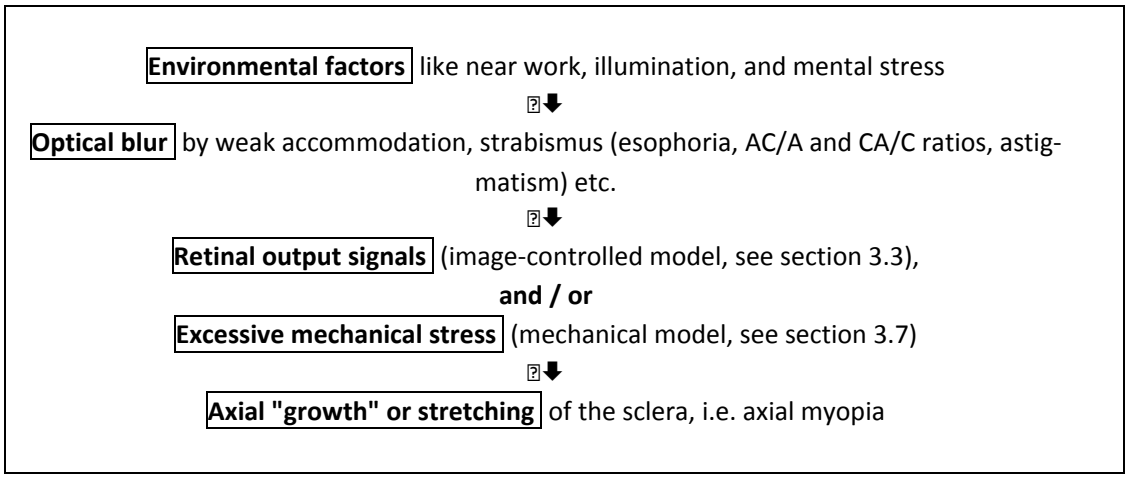

Environmental factors like near work, illumination, and mental stress
Optical blur by weak accommodation, strabismus (esophoria, AC/A and CA/C ratios, astigmatism) etc.
Retinal output signals (image-controlled model, see section 3.3),
and / or
Excessive mechanical stress (mechanical model, see section 3.7)
Axial "growth" or stretching of the sclera, i.e. axial myopia

Figure 13 Paths to myopia

There exists a **quantitative mathematical model** in which the interactions between accommodation, vergence and optical blur were used to explain the development of emmetropization and myopia[395].

Notes:

- *This sequence looks rather straightforward. What appears to be **missing** frequently in the literature is the consideration of the fact that (especially highly) myopic eyes have **substantial structural and biochemical deficiencies and anomalies**, and that therefore the feedback mechanism as outlined above is not working in a moderate manner, but often excessively with some **pathologic** attributes. And why exactly is this chain of events **not having any impact on some people at all?***
- *Obviously, the knowledge of the interaction between the "opto-mechanical world" and the biochemical world is still missing. Nutrition (see section 3.24) might be one of the keys.*
- *Maybe there are **blood sugar** related effects on the AC/A ratio as well (see section 3.24.2).*

3.6 Saccades and Focusing

To focus an object, the eye is making **about 30 to 80 fast eye movements (oscillations) per second**, with an angle amplitude of about 10" to 30" (one " equals to 1/3600 of one degree)[478]. The purpose is to trigger permanently the sensitivity for contrast. Images are said to become grayish on the retina if the stable focusing is longer than 1 to 2 seconds. These saccades are said to play a role in the interaction accommodation / vergence, too[479].

Some people (not really the scientific world) are recommending special training glasses with a pattern of fine holes in a dark surface, called pinhole glasses, to encourage the eye to perform these saccades.

Note:
*In the scientific literature about myopia research there is **hardly any mention of saccades**, which is rather astonishing, as it appears to be essential for image acuity, and appears to be quite related to the experiments, where induced myopia in animals was successfully reduced by flickering light[324]. Additionally, excessive saccadic movements might cause **additional oxidative stress.***

The myopic eye has a specific problem correlated with saccadic eye movements, as David et al. stated[480]: " ...if account is taken of the increased force required to provide normal saccadic movement of myopic (larger) eyes, then the **shear force** [a force that occurs in the thin eye wall shell supporting the vitreous body] is up to **seven times greater** than that experienced for emmetropes."

Note:
This additional force for saccadic movements might create two problems:

- *If the extraocular muscles cannot sustain this additional power, a **degraded image** and/or focus might result again, contributing to a further **progression of myopia**.*
- *Due to this **increased force**, which is necessary for the myopic eye, a **progression of** myopia could be caused, according to the thesis presented in section 3.7.*

For myopes with **more than 6 D** a significantly **slower eye velocity in saccadic movements** was found, and if (soft) **contact lenses** were used instead of glasses, a significantly slower eye velocity was recorded as well. A potential explanation was the additional mechanical effort due to the increased mass.[481]

High-frequency microfluctuations of accommodation were reported for thicker ciliary bodies[482], and the thickness of the ciliary body was found to be positively correlated with myopia[535].

Moreover, **glucose metabolism** has an impact on the saccadic eye movements[483, 484], e.g. diabetic patients have **disturbed saccades** (asymmetry between the two eyes, longer latency). For the impact of the glucose metabolism on myopia see section 3.24.1.

Hartwig et al., however found[485]: "Durations, amplitudes, and peak velocities of the main saccades and the numbers of overshoots, undershoots, and exact fixations were analyzed. For all analyzed parameters, no significant differences were found between myopes and emmetropes. … In myopes, only the peak velocity showed a weak correlation with refractive error and axial length, but this failed to reach statistical significance when allowance was made for multiple testing."

Ghasia et al. reported[486]: " We found an **increase in the amplitude of microsaccades in the presence of uncorrected refractive error**, but the microsaccade frequency and velocity remained unchanged. The **microsaccade amplitude systematically increased with an increase in uncorrected refractive error**."

Goffart et al. found[487] by experiments with monkeys that **saccade movements were significantly different depending on the level of illumination.**

Yang et al. reported[488]: " The results show poor binocular **coordination of saccades in children is distance dependant: coordination is particularly poor at near** and could compromise single binocular vision;"

3.7 Mechanical Properties, Stress, Strain and Pressure

3.7.1 Impact of Mechanics on Biochemistry

Theories, which are attributing myopia exclusively to image related effects, or biochemical effects, or mechanical effects are not necessarily in competition with each other: It is still an open question whether the process leading to a degradation of the sclera is completely biochemical, and the reduced mechanical stability of the sclera is simply the effect of a changed biochemistry, or whether mechanical forces are initiating biochemical modifications (a process called **mechanotransduction**), which lead to the degradation[346]. There can be also a combination of both effects.

This model was supported by the result that **scleral fibroblasts** (i.e. cells of the connective tissue), **which were mechanically stretched, showed significant changes in gene expression.** These changes were already observed after 30 minutes of stretching[186]. This time length is typical of near-work accommodation.

*Baumert et al. reported[708]: "Prolonged unaccustomed **exercise involving muscle lengthening (eccentric) actions can result in ultrastructural muscle disruption, impaired excitation– contraction coupling, inflammation and muscle protein degradation**.*

Note:
*Accommodation generally results in a temporary elongation, i.e. stretching of the sclera of the eye (see sections 3.2.1.1 and 3.30.2). Conclusion: **Accommodation can result in gene expression of scleral fibroblasts.***

3.7.2 Intraocular Pressure (IOP)

Overall, there is a general agreement in the literature that a **higher intraocular pressure is associated with myopia**[489, 490, 491, 492, 493].

A newer report came to the opposite conclusion. SM Liet al. reported[494]: "In this sample of Chinese children, **myopia progression over 2 years was inversely related to IOP**, suggesting that IOP had essentially no relationship with myopia progression in school children. **The lower IOP in progressing myopic eyes may indicate more compliant sclerae."** In other words, **a degraded connective tissue of the sclera is typical for progressive myopia.**

The impact of accommodation on the IOP was explained by Viikari K[495]: "**The accommodation spasm strains and swells the accommodation muscle** (m. ciliaris, whose processus ciliares are responsible for secreting the aqueous humor). Also, the lens of the eye thickens, producing stronger refraction. *On top of not working in an ideal fashion, these swollen anatomical structures take up space* and narrow the angle: the circulation and outflow of the aqueous humor are decreased, and the **intra-ocular pressure increases**."

Correspondingly, in section 3.2.1.2 research results were summarized that **accommodation results directly in an elongation of the eye**.

Note:

Myopia, i.e. the stretching of the eye might be explained by simple mechanical stretching by an increased IOP:

For **children aged 9-11 years, however, no association between IOP and myopia** was found in one study[496], **whereas** another study by Lin et al. stated[497] that "...**IOP of patients less than 19 yrs is significantly higher** than patients more than 30 yrs..."

Note:

It is claimed that with new technology the measurement of the IOP is completely independent from the rigidity of the sclera, but maybe there are still limitations of the measurement process ("completely independent" is hard to believe from the point of physics).

Yan L et al. reported[498]: **There was no significant difference in IOP between progressing myopes and emmetropes when no accommodation was induced** (16.22±4.11 vs 17.01±3.72, respectively, t=-0.93, P>0.05). **However, IOP significantly increased with accommodation in progressing myopes** (mean change +1.02±2.07mmHg from 0D to 6D, F=5.35, P<0.01), but remained unchanged (mean change -0.76±3.22mmHg from 0D to 6D, F=1.46, P>0.05) in emmetropes."

Notes:

- *This increased IOP for progressing myopes has to have an increased stretching effect on the sclera.*
- *Ist there a difference in the working of the ciliary muscle the reason of this increased IOP? It looks like this is the case:* Pucker AD et al. reported [521]: "… in children the posterior ciliary muscle fibers are thicker in myopia … but paradoxically, the apical ciliary muscle fibers are thicker in hyperopia."

Consequently for myopes there is an elevated probability of glaucoma[499]; a study showed typical probabilities for glaucoma of 1.5% for eyes without myopia, 4.2% for low myopia and 4.4% for moderate to high myopia[500].

When people with **progressive myopia** do near work, there is an uncompensated **hyperproduction of intraocular fluid**, which causes elevated ocular hypertension because there is an insufficient outflow[173]. Correspondingly, for the time of recovery from experimental myopia an **increase in the fluid outflow** during emmetropization was found[501].

A **general increase** of IOP with **accommodative stress**[258] and with **accommodation and convergence** to close distance[502] was found.

In contrast, Read SA reported[503]: "**IOP [intraocular pressure] decreases significantly with accommodation, and changes similarly in progressing myopic and emmetropic subjects**."

Some authors, however, state that **a higher IOP follows the onset of myopia and does not cause myopia** [504, 505].

Note:

Is the structural change of the myopic eye's connective tissue also blocking the fluid to flow off, causing an elevated IOP?

Experiments have shown that growing eyes of chickens elongate during the day and shorten during the night, which correlates with the IOP (high at daytime, low at night). There were, however some phase differences between the rhythms in IOP and ocular elongation – with the IOP ahead of the elongation. It was therefore proposed by Nickla et al.[626] "**that the rhythm in IOP influences ocular elongation in ways other than by simply inflating the eye, for example, by influencing underlying rhythms in scleral extracellular matrix production.**"

Notes:

- *The observed phase difference between IOP and elongation could as well be explained by the effect of a **hysteresis of the mechanical properties** of the connective tissue.*
- *On the other hand, the pressure within the eye is uniform, but the control of the length of the eye due to emmetropization (section 3.3.5) can be **very local** as well, if this serves a better image quality. This is an argument against a completely IOP-driven myopia.*

One author claimed to have success in treating myopia with the IOP-lowering **beta-blocker** metipranolol[506], but other authors could not confirm this by using the different beta-blocker timolol[507].

From other experiments it was concluded that a higher IOP affects **neuronal functions** of the eye[508].

Note:

This would give a link with the fact that myopia is connected with dopamine metabolism and elevated IOP.

Several components of nutrition were found to be able to influence the IOP[492]:

Rutin, a bioflavonoid was reported to lower IOP[509].

A deficiency of chromium was reported to increase IOP[510].

Elevated blood glucose was reported to increase IOP[511].

Folate from food was reported to lower IOP[512].

All these dietary components were related to myopia besides their impact on IOP (see section 3.24).

Moreover, an elevated IOP appears to be highly related to emotional effects and stress[513], i.e. sensitive people are more at risk of an elevated IOP (see section 3.19 for the impact of stress on myopia, and section 3.19.2 for the relation between personality and myopia).

A study by Lee et al. [514] "identified a modest cross-sectional **positive association between current smoking and intraocular pressure**."

3.7.3 The Ciliary and other Muscles

In section 3.2.1.2 it was already described in some detail, that **accommodation causes an elongation of the eyeball.**

Long ago Bates[515] claimed and showed respective experiments that **the oblique muscles of the eye, which are responsible for the movement of the eyeball can lengthen the eye**, in other words can create temporary myopia.

These oblique muscles are part of surgery for **strabismus**, which demonstrates, that during convergence for near work there will be substantial load on these muscles.

Greene [516] has explored whether the elongation of the eyeball can be simply explained mechanically, by "the **stresses** experienced by the posterior sclera as a **result of accommodation, convergence, vitreous pressure, and the extraocular muscles**."

Basis of the engineering-like analysis was that:

Substantial forces are applied to the eyeball, e.g. the **extraocular muscles** can generate 150g (peak) and routinely produce 40g during large amplitude **saccades**[517] (see section 3.6 about saccades). In contrast, the force applied by the ciliary muscle was found to be only 0.6g.

Congenital nystagmus, which is characterized by extreme saccadic movements, is mostly accompanied by myopia[518].

A substantial increase of the **intraocular pressure** (IOP, see section 3.7.2) of up to additional 14mm Hg was found during accommodation and convergence at close distance[519].

The relationship between ciliary muscle thickness (CMT) and myopia was investigated by Buckhurst et al.[520]: "**Increased CMT is associated with myopia. We speculate that the lack of correlation in myopic subjects between CMT and axial length, but not between CMT and OV [ocular volume],** is evidence that disrupted feedback between the fovea and ciliary apparatus occurs in myopia development."

Bailey et al. reported[535]:"**Thicker ciliary body measurements** were associated with myopia and a longer axial length."

Pucker AD et al. reported more dtailed results[521]: "… in children the posterior ciliary muscle fibers are thicker in myopia … but paradoxically, the apical ciliary muscle fibers are thicker in hyperopia."

McCollim's experiments showed[522] that the **oblique muscles** of the eye and the stress on them are essential for at least temporary elongation of the eye.

Wu S reported[853]: "We found **that the arrangements of ciliary muscles in LIM [lens induced myopia] guinea pigs were broken, dissolved or disorganized** …. Monitoring of K [potassium] flux in ciliary muscles from LIM guinea pigs demonstrated myopia-triggered K influx."

The fact that **nearwork-induced transient myopia (NITM) is substantially greater at myopic children, and shows a longer regression time**[523] is an indication for the involvement of the muscular system in myopia by muscular spasms.

The result of the analysis was that the **mechanical forces are strong enough** to explain the elongation of the eyeball seen in myopia. There are a variety of individual geometrical parameters (like geometrical arrangement of the muscles) and material-dependent parameters (like the quality of the connective tissue of the sclera), which can explain, why not everybody who is doing a lot of near work is becoming myopic (there is a lot of individuality for parameters like this[524]).

In other words: Myopia can be explained as the result of the joint effects of **muscular force and hydraulic pressure (IOP) on a weakened tissue structure**.

A specific theory about the interaction of the muscles was mentioned in section 1.3.2.4.

Notes:

- *The alternative theory of accommodation mentioned in section 1.3.2.4 is similar to this analysis - both are emphasizing the effect of the extraocular muscles.*
- These results are in line with the alternative model that myopia is primarily caused by excessive accommodation force (see section 3.2) in contrast to the current research, which is focused almost entirely on the model of image degradation and related biochemical signaling.
- *The long term, substantial load on ocular muscles can contribute to a **degradation of the connective tissue** of the sclera via an elevated **temperature** (see section 3.16). Near work was in fact found to increase the temperature of the eye (see section 3.2.1).*

3.7.4 The Lens

There exists another potential mechanical model, which might be used to explain myopia. Points to consider are:

As reported in section 3.2.1 there is a **time delay for the return of a myope's lens shape** after accommodation (referred to as hysteresis).

The experiment reported in section 1.3.2.4 showed that it can **take very long (several years!) until a lens goes back to its original shape**, if the accommodative stress was long lasting.

Mutti D et al. reported[525]: "Before myopia onset, the crystalline lens thinned, flattened, and lost power at similar rates for emmetropes and children who became myopic. **The crystalline lens stopped thinning, flattening, and losing power within ±1 year of onset in children who became myopic compared with emmetropes** statistically adjusted to match the longer VCDs [vitreous chamber depth] of children who became myopic."

Together with the (optical) model of negative-lens-induced myopia (see section 3.3) a hysteresis of the shape of the lens might:

Induce myopia by blurring the image when focusing a distant object, but when the lens is still at a residual accommodative state

Induce myopia by an inappropriate negative lens, which is fitted according to this transient residual accommodative state.

This hysteresis of the shape of the lens might be caused by an effect of the **ciliary muscle**, or by an effect of the **elasticity of the lens**.

No information exists about what might cause different modes of elasticity of the lens for myopes and non-myopes; maybe the swelling of the lens in a hyperglycemic state contributes to this effect (see section 3.24.1).

3.7.5 The Pupil Size

Tsukahara et al. reported[526]: "We found that fluid intelligence [Fluid intelligence is defined as reasoning ability, and the ability to generate, transform, and manipulate different types of novel information in real time[527]], working memory capacity, and attention control did correlate with baseline pupil size except in the brightest lighting conditions. … We conclude **that fluid intelligence does correlate with baseline pupil size and that this is related to the functional organization of the resting-state brain through the locus coeruleus-norepinephrine system.**"

Note:
Large pupil size means reduced image quality as for a camera lens with large aperture (depth of focus effect). Now we learn that the larger pupil, which results in reduced image quality, ***which is correlated with myopia*** *correlates with higher fluid intelligence****. In short, higher intelligence may result in higher likelihood of myopia.***

larger pupil ⇨⇦ *more intelligence*

⇩

reduced image quality ⇨ *myopia*

3.7.6 The Ocular Shape

Some results about the ocular shape are:

Schmid et al. stated[528]: "Eye shapes (a) **varied substantially among subjects** and (b) differed considerably from the corresponding shapes of spherical model eyes with identical axial eye lengths.".

The ratio of the length to the transverse dimension in eyes shows that the higher the myopia the higher the ratio, i.e. the eye is **stretched primarily in length**[529].

Partial coherence interferometry was used to measure the eye. The result showed that **the eye generally elongates during accommodation**, with this explanation by Drexler et al.[28]: "… by the accommodation-induced contraction of the ciliary muscle, which results in forward and inward pulling of the choroids, thus decreasing the circumference of the sclera, and leads to an elongation of the axial eye length … the elongation was more pronounced in emmetropes than in myopes".

Collins MJ et al. summarized their measurements[530]: "**Small but significant increases in axial length were evident during and to a lesser extent, immediately after the accommodation task**."

Notes:

- *To understand this model, just think of a balloon, which is squeezed, and which expands consequently in the other direction.*
- *The result that emmetropic eyes elongate more during accommodation appears astonishing and leads to the conclusion that not only mere mechanical effects are responsible for myopia.*

There is a substantial **hysteresis of the ocular shape**: Walker et al. stated[190] that with normal people, **after accommodation "... ocular shape had become more prolate [i.e. stretched].** This shape remained unchanged after 1 hour of sustained accommodation and then returned to baseline dimensions after 2 hours of accommodation ... Ocular shape returned to baseline dimensions after 45 min of accommodative relaxation." See also section 1.3.2.4 about the impact of accommodation on the ocular shape.

Note:

*This hysteresis should be a major problem for the accuracy of refractive measurements for fitting glasses. One could even consider this elongation with accommodation as some kind of "**slow accommodation**". It appears rather plausible that with extensive near work, this **elongation becomes permanent, which corresponds to myopia**.*

Mutti et al. stated[531]: "The eyes of myopic children were both elongated and distorted..." ... "Increased **ciliary-choroidal tension** is proposed as a potential cause of ocular distortion in myopic eyes."

Notes:

- *If an ocular body has a **weak support by the connective tissue,** the increased ciliary-choroidal tension and the **increased hydraulic force** during extended accommodation could explain the permanent axial extension: In the transverse direction the ocular shape is maintained by the ciliary muscle, but there is less or insufficient support in the axial direction (length) of the eye. The weak connective tissue might be correlated to the effects mentioned in section 3.3.2 and 3.24.16.*

- *Can a specific **inborn ocular shape** cause an increased risk of developing myopia (e.g. via different resulting stress on the ciliary fibers)?*

Schaeffel summarized[532] "Taking all studies together, there is convincing evidence that **thickening of the choroid predicts future inhibition of eye growth**, while thinning predicts future myopia development."

Note:

On one hand is appears just plausible that elongation and thinning of the sclera is accompanied by a thinning of the choroid, on the other hand this thinning of the choroid, which supplies the surrounding tissue with oxygen might be interpreted as an indication for the importance of the blood circulation (see section 3.17).

For Eskimos and for Chinese, both populations with an elevated rate of myopia, the anterior chamber angle declines more rapidly with age[533].

For more information about the effect of accommodation on the axial length of the eye see section 3.2.1.2.

3.7.7 The Zonular Fibers

Note:
The following model has apparently not been discussed in the literature, but seems to be plausible:

If the zonular fibers (which are attached to the lens, and whose pulling action on the lens regulates accommodation, see section 1.2) are lacking strength and elasticity, they have a problem in pulling the lens into a flat shape when the ciliary muscle relaxes. The result will be a ***myopic refraction, leading to the prescription of glasses even if the eyeball is not elongated*** *yet, or to a blurred image with potentially corresponding negative effects (see section 3.3).*

Furthermore, ***reduced accommodation amplitude*** *can be expected.*

The basic reason for the weakness of the zonular fibers should be weak, degraded connective tissue. Weak, degraded connective tissue is closely related to myopia, especially to progressive myopia (see e.g. sections 2.2, 3.18.9).

3.8 Relations between the Dimensions of the Cornea, the Crystalline Lens and the Ciliary Muscle

The refractive power of the cornea shrinks from 47 to 48 D in infants to 43 to 44 D by the age of 3 to 9 months and remains afterwards rather stable[534].

The crystalline lens experiences by far more laterations. The lens power shrinks from 41 D in infancy to 22 to 23 D at the age of 14 years[534].

At emmetropes, the change of the optical parameters of the corneal- /lens-system and the axial growth takes place in a well-coordinated manner, i.e. as well myopia as well as hyperopia are avoided.

Mutti et al., reported that this balance is disturbed at the onset of myopia[534]: **"The ocular components that are in balance in emmetropia are obviously out of balance in myopia: the eye is too long for the optical power of the cornea and crystalline lens." and "The crystalline lens ceased to thin, flatten, and lose power even as the eye continued to grow."**

Possible explanations they are giving are:

- **Peripheral defocus** influences the balanced growth of the eye (see section 3.3.11 about peripheral defocus).

- **Extensive growth of the ciliary muscle**.
  Bailey et al. reported[535]: "Thicker ciliary body measurements were associated with myopia and a longer axial length." Mutti et al. concluded[534]: " The abnormally thick ciliary muscle for a given axial length in myopia may provide the mechanical restriction that would interfere with the equatorial expansion needed to maintain the correlation between ocular growth and optical compensation by the crystalline lens. Anterior mechanical restriction may limit far peripheral expansion, resulting in the relatively more prolate ocular shapes found in myopic eyes."

The mentioned publications do not answer the question whether the increase of dimensions is caused by growth or by stretching. In section 3.9 this issue will be discussed.

Note:
As the ciliary muscle is in charge of accommodation the question arises, whether extensive near work and extensive accommodation are in fact essential contributors for the onset of myopia.

3.9 Growth or Stretching and Thinning or Biochemical Thinning of the Sclera in Myopic Eyes?

- **Growth means** extension by adding new cells,
- **stretching and thinning means** an extension of existing structures with consequent thinning,
- **biochemical thinning means** a loss of substance with a subsequent thinning due to biochemical, not mechanical processes.

In section 3.2.1.2 it was already described that accommodation causes at least a temporary elongation of the eye.

Sergienko reported the results of the examination of 172 eyes of 86 subjects[536]: "The hypermetropic and emmetropic eyes possessed stiff sclera. … The absolute majority of the myopic eyes revealed a biomechanical weakness of the scleral shell. A higher degree of myopia was associated with increased AL elongation."

Form-deprivation resulted in the building of hypertrophic cells (chondrocytes), i.e. in the enlargement of cells instead of the building of new additional cells[358]. In other words, there is no growth, but a stretching by a degradation of the quality of the tissue.

Scleral fibroblasts (i.e. cells of the connective tissue), which were mechanically stretched, showed significant changes in gene expression. These changes were already observed after 30 minutes of stretching[186]. This time length is typical of near-work accommodation (see section 3.7.1).

Nickla Dl et al. stated[537]: "In chicks, ocular growth inhibition is associated with choroidal thickening and growth stimulation with choroidal thinning, suggesting a mechanistic link between the two responses."

In section 3.16 it is described that an elevated temperature causes a degradation of the connective tissue, and that feverish sicknesses of children are often followed by the onset of myopia, and that intensive accommodation increases the temperature of the eyeball.

McBrien summarized[356]: "Analysis of the dry tissue weight of the sclera has demonstrated that the cause of scleral thinning in myopia is due to actual loss of scleral tissue as opposed to simply passive stretch of the sclera."

Note:
Even mechanical stretching alone, however, would result in a thinning of the sclera with a corresponding loss of tissue density.

All these facts lead to the conclusion that myopia is not accompanied by a "growth"- elongation of the eye, but clearly by a stretching, either by biochemical degradation and / or by added mechanical force.

Obviously, when permanent stretching and a degradation of the connective tissue was already taking place it can hardly be expected that it can be reversed, and in case it caused already a structural weakening there is a probability of progressing myopia.

This could explain negative results of plus lenses for children, which already became myopic, and whose sclera is already changed in its mechanical properties.

Why are some people not becoming myopic even when doing excessive nearwork? It could be explaned by an individual connective tissue of the sclera, which has elastic properties and no plastic properties, i.e. the stretching is not permanent and like a rubber string, in contrast to the plastic properties like a piece of dough.

According to the stretching / thinning model, the eye can be compared to a balloon, which is expanded by accommodation, especially extended accommodation.

For eyes with a very elastic sclera the "balloon" will return to its original size after the accommodation-load, for eyes with a more plastic sclera the expansion will tend to be permanent.

The conclusion is that the use of plus lenses to avoid accommodation spasms and permanent stretching has to start before the stretching begins, i.e. it has to be preventative to be effective.

Note:
Following the degradation / stretching / thinning model, this stretching might be caused by:

General weakness of the connective tissue of the sclera, and / or local degradation of the scleral tissue caused by an image-quality-guided biochemical process
↓
Muscular tension by accommodation / intraocular pressure
↓
Ocular elongation

The question where growth ends and where stretching begins was investigated by Chung[538] et al. They found that stretching begins between 25.6 and 26 mm axial length, which corresponds with about 5 to 6 D, which means pathological myopia begins at about 6 D.

3.10 Outdoor Activities

Outdoor activities were found to have a substantial positive effect on the prevention of myopia or the reduction of the progression of myopia as numerous papers showed[539, 540, 541, 542].

Rose et al. reported[543]: **"Higher levels of total time spent outdoors, rather than sport per se, were associated with less myopia and a more hyperopic mean refraction, after adjusting for near work, parental myopia, and ethnicity." It can be concluded that this fact is due to the relaxing effect of the time spent outdoors."** Furthermore, they speculated that the positive effect of outdoor activities is caused by the release of the retinal transmitter **dopamine** (see section 3.3.3about the effect of dopamine on myopia).

Guggenheim et al. reported[544]: "Thus, for children nonmyopic at age 11, the **hazard ratio** (95% confidence interval, CI) **for incident myopia was 0.66** (0.47-0.93) **for a high versus low amount of time spent outdoors, and 0.87** (0.76-0.99) per unit standard deviation above average **increase in moderate/vigorous physical activity.** Conclusion: Time spent outdoors was predictive of incident myopia independently of physical activity level.

Fong K summarized[545]: "the 2005 Sydney Myopia Study showed that while Chinese pupils in the city did more near work than their Singapore counterparts, they had fewer cases of myopia. Researchers suggested that this **was due to Sydney pupils having four times more physical activity compared to students in Singapore**."

Even having just **outdoor activities during school class recess** were found to have a significant effect on myopia onset and myopia progression at Taiwanese children[546].

McBrien, Morgan and Mutti[547] summarized presentations from the 12th International Myopia Conference 2008 as the hot topic:

- **"... recent evidence that children who spend more time outdoors are less likely to become myopic as one of the most significant findings reported."**
- **"... have shown that children with the risk factor for myopia of myopic parents, are at only slightly greater risk than children without myopic parents if they spend sufficient time outside."**
- **"... suggest that greater time spent outside can also over-ride the greater risk associated with near work and schooling."**
- **"... suggesting that the effect is likely to be seen in children from all ethnic groups. The agreement between these studies is unusual in the area of the etiology of myopia, which is generally renowned for its controversies, rather than for consensus."**
- **"... Firstly, protection does not seem to result from a "substitution" effect, in which children replace time spent on reading and writing and other forms of near work with outdoor activities. Secondly, the critical factor seems to be total time outdoors (in daylight hours), rather than sport or physical activity, since indoor sporting activities are not protective, while both active and more passive activities outdoors are. The studies are in rough agreement on the protective exposures - around 2 to 3 hours a day outside of school hours seems to be sufficient to markedly lower the risk of myopia."**

Notes:

The positive effect of outdoor activities ccould could be based on these issues:

a) *the reduced load of accommodation – in general zero accommodation (see section 3.2)*
b) *the elevated level of dopamine (see section 3.3.3)*
c) *the additional amount of vitamin D which is generated by the sunlight (see section 3.24.3)*
d) *the level of illumination which is normally higher outdoors (see section 3.14.1)*
e) *the color of illumination, as the outdoor illumination has a shorter wavelength than most of the artificial indoor illumination (see section 3.14.2*
f) *UV A light induces elevated NO levels[548], for the impact of NO on myopia see section 3.18.7)*
g) *UVA light and riboflavin improves the cross-linking of the collagen in the sclera and herewith* the stability of the sclera against stretching (3.18.8)
h) *enhanced physical exercises (see section 3.13)*
i) *reduced mental stress (see section 3.19.1)*
j) *children with frequent outdoor activities have a more extroverted mentality in general (see section 3.19.2*

Since "indoor sporting activities are not protective", the explanations given under b) to g) appear to be more convincing, as the other potential explanations would apply to indoor sporting activities as well.

Walline reported, however[298]: "… outdoor time has shown to be effective for reducing the onset of myopia but **not for slowing the progression of myopic refractive error**."
This was confirmed by studies published by Li SM[549].
In contrast, Jin found that outdoor activities **can as well slow down the progression of myopia**, in his study from - 0.27 ± 0.52 D/year form the control group to - 0.10 ± 0.65 D/year for the group with additional outdoor-time[550].

Note:
An explanation for the result that the progression was not slowed down can be that f) and g) are responsible for the positive effect of outdoor activities, UV-light, however, is not reaching the eye (i.e. the sclera) at people wearing glasses or contact lenses, as these materials are generally eqipped with UV-blockers. Maybe in some trials the children took off their glasses for the outdoor activities.

Outdoor activities are easier to do and are more common for people, who live in rural areas than for those in the cities, which contributes to the fact that myopia is more widespread in the densely populated cities.

In sections 3.1 and 3.24.3 it is summarized: "An evaluation of statistical data for reported blindness due to malignant myopia in different states of the USA was done by compiling a chart with the rate of myopia per state, and distance to seacoast, annual hours of sunshine and the nutritional concentration of calcium, fluoride and selenium in each state. One result was an inverse correlation between malignant myopia and calcium content in the water as well as annual hours of sunshine[96].

A longer time spent outdoors is also an indication of a higher exposure to sunshine.

See also

- section 3.14 about **Level Illumination / Light / Day- and Night**-Rhythm, and
- section 3.3.3 about the role of **dopamine** in the onset of myopia

3.11 Exposure to Bright Sunlight

McKnight et al. reported[551]: "myopic refractive error was inversely associated with objectively measured ocular sun exposure … There was an inverse relationship between myopic refractive error and ocular sun exposure, with more than double the prevalence of myopia in the lowest quartile of conjunctival autofluorescence than the highest quartile (33.0% vs 15.6%)".

Note:
These results can at least partly explain the high incidence of myopia in Asian countries, where exposure to the sunlight is traditionally avoided.
The current fright of skin cancer adds to an increase in the onset of myopia.

3.12 Seasonal Impact

Mandel stated[818]: "There were seasonal variations in moderate and severe myopia according to **birth month**, with prevalence highest for June/July births and lowest for December/January ... Mild myopia was not associated with season of birth or perinatal light exposure."

Donovan et al. summarized their results[552]: "**Myopia progression in summer months was approximately 60% of that seen in winter**, and axial elongation was likewise significantly less in summer. It is unclear whether more time spent outdoors in summer vs. winter is a contributing factor, or the difference in progression rates is a result of "seasonal" variations in the intensity or amount of close work performed."

Cui D et al. reported the results of a clinical trial with 235 children 8 to 14 years old[553]: " **Eye elongation and myopia progression seem to decrease in periods with longer days and to increase in periods with shorter days**."

Gwiazda J et al.[554] reported for myopic children 6 to 12 years old a mean progression of – 0.35 D in winter and –0.14 D in summer. This was attributed to the children's **extended time spent outdoors in summer**.

3.13 Physical Exercises

No direct correlations between myopia and physical exercises are available. Two results, however, are giving strong indications:

In **urban areas** myopia rates are higher than in rural areas (see section 3.1). Generally people in the city have less physical activity than people in the countryside.

(Sure, there are many other differences. For example, immune system would be healthier in the country, more Vitamin D, less reading...)

All forms of physical exercises reduces the **intraocular pressure (IOP)**[555]. For the impact of the IOP on myopia see section 3.7.2.

Okuno et al. reported[556]: "**Dynamic exercise ... produces increased tissue blood flow in the retina in the immediate post exercise period, while blood flow increases more persistently in the choroid-retina**." and "**The plasma NO metabolite levels increased significantly**."

For the interrelation between the blood circulation and myopia see section 3.17, for the interrelation between NO metabolism and myopia see section 3.18.7.

In a study, which confirmed the positive effect of outdoor activities, it was found that indoor sports do not have a positive on the development of myopia[557].

Read SA et al. reported[558]: "Myopic children exhibit significantly lower daily light exposure, but no significant difference in physical activity compared to emmetropic children. This suggests the important factor involved in documented associations between myopia and outdoor activity is likely exposure to bright outdoor light rather than greater physical activity."

3.14 Illumination / Contrast / Light / Day- and Night-Rhythm

3.14.1 Level of Illumination

Some results about the impact of the level of illumination are:

The progression of myopia of school kids is **slower during summer holidays**[150, 151, 152]. This might be attributed to the brighter light in summer.

Cui et al[559]. reported that the progression of myopia for children in Denmark depends strongly on the day length. For an average of about 2782 hours of daylight the axial eye growth was 0.12 mm, for about 1681 hours of daylight the axial eye growth was 0.19 mm.

A once promoted theory by Trichtel was that excessive **heating up of the background of the eye** (or the whole body) is responsible for myopia[7]. The eye was said to be overheated because of **too much incident light through over-large pupils**. It was said that this large opening of the pupils is common to all myopes (claimed to be based on many references), and is additionally caused by stress. At near accommodation the width of the pupil of myopes was said to be even larger than of other people.

Newer publications, however, report that the opening of the pupils of myopes is not wider[560, 561], and that low levels of light can help myopia to progress[331, 562]**.** Generally the pupil is narrow-

ing when accommodation is occurring[563]; maybe this was helpful during evolution of mankind to use better depth of focus for near objects (each photographer knows that depth of focus is a problem for near objects, which can be solved by a smaller aperture of the iris of the camera).

Overall, this theory of Trichtel can be considered refuted.

An evaluation of statistical data for reported blindness due to malignant myopia in different states of the USA was done by compiling a chart with the rate of myopia per state, and distance to seacoast, annual hours of sunshine and the nutritional concentration of calcium, fluoride and selenium in each state. **One result was an inverse correlation between malignant myopia and calcium content in the water as well as annual hours of sunshine**[96].

A test with monkeys (already in 1961)[156], whose visual space was restricted to an average of fifteen inches, showed that all of them developed some myopia, but that **groups with high and low level of illumination showed less myopia** than the one with medium level illumination. The high level matches about the number of 300 Lux for reading, the medium level matches a level "provided in a ten by ten foot room with an eight foot ceiling and a 100 or 150 Watt bulb at the ceiling" as Young stated[156] – which is considered to be common for reading. The illumination level of the low level group made reading impossible.

Note:
These results are similar to the one found about thirty years later when the deprivation issue and the effects of an inappropriate minus lens were discovered as initiators of myopia.

If the eyes of chicken were covered with plastic sheets that produce a hardly noticeable degradation of the image quality on the retina, no myopia developed at an illumination level of 500 Lux. If the illumination level, however, was reduced to 5 Lux a myopia of –5 D developed within 10 days.

Similarly, myopia developed when, at a surrounding brightness of 500 Lux, the animals received sunglasses that reduced the incidence of light on the retina by a factor of 100. If only one eye is treated with the sunglasses, only this eye is becoming myopic[564, 565].

Ashby R et al. reported[566]: "Exposing chicks to high light levels, either sunlight or intense laboratory lights, retards the development of experimental myopia. These results, in conjunction with recent epidemiologic findings, suggest that daily exposure to high light levels may have a protective effect against the development of school-age myopia in children."

Ashby and Schaeffel[567] summarized their experiments with chicks: "… the development of **deprivation myopia was also significantly suppressed under bright light**, even though depth of focus does not play a role under the diffusers." … "High illuminance levels reduce the rate of compensation for negative lenses and enhance the rate for positive lenses, but do not change the set point of emmetropization (target refraction). The retardation of myopia development by

light is partially mediated by **dopamine**, as the injection of a dopamine antagonist abolishes the protective effect of light, at least in the case of deprivation myopia."

Note:
From the fact that the compensation for positive lenses is increased at high levels of illumination, it can be concluded that ***the use of plus glasses for near work in combination with bright illumination is beneficial.***

Ashby R and Morgan I reported[568]: "Exposing chicks to high light levels retards the development of experimental myopia and reduces the rate of compensation for negative lenses, but enhances the rate of compensation for positive lenses. **The retardationof deprivation myopia by light is mediated, in part, by dopamine** …"

Moore et al. summarized their results[569]: "Reducing light levels effectively reduces the contrast of the visual environment. Reducing contrast has been found to produce myopia, and our results agree."

Schmid KL et al. came to different conclusions, however[570]: "Our data do not support the suggestion that common reductions in letter size or contrast of reading material (as might occur for photocopied reading materials) cause greater accommodation inaccuracy and greater near work-induced adaptation effects that would exacerbate myopia development in young adults."

A result by Feldkaemper et al. [331] from the experiments about myopia caused by low image quality is: "… **the eye becomes more sensitive to image degradation at low light, the human eye may also be more prone to develop myopia if the light levels are low during extended periods of near work**".

It was also described[7] that a higher level of **illumination increases significantly the capability for accommodation**, and that presbyopes (i.e. older people with reduced accommodation) can read more easily in high illumination – clearly independent from the increased depth of focus, which is caused by a narrower opening of the pupil.

On the other hand, generally the **accuracy of accommodation decreases with decreasing brightness**[564] (which resembles the depth of field of cameras).

The development of chicks towards emmetropization was observed at various levels of illumination[571]: (10.000 Lux, 500 Lux and 50 Lux). **Result: After 90 days 50 Lux resulted in a mean myopia of –2.41 D, 500 Lux resulted in +0.03 D, and 10.000 Lux resulted in hyperopia of +1.1 D.**

Cohen Y summarized their results: "Thus, under light-dark cycles, light intensity is an environmental factor that modulates the process of emmetropization, and **the low intensity of ambient light is a risk factor for developing myopia**."

Similar results were obtained from experiments with monkeys at illumination levels of 15-630 lux (which corresponds to normal lighting levels) and 25,000 lux for 6 hours a day. The explanation of Smith EL et al. is[572] "These results are in agreement with the hypothesis that the protective effects of outdoor activities against myopia in children are due to exposure to the higher light levels encountered outdoors."

Backhouse et al. compared the development of myopia at chicks by monocular deprivation[573]: "… groups received either constant 2000 lux (n = 11) during the light period or 300 lux for 10 h with a 2 h period of bright light (10 000 lux), either in the morning (n = 10), midday (n = 10) or evening (n = 10), giving the same total daily light exposure as the 2000 lux group." Results: "Myopia in the constant 2000 lux group (-4.94 ± 1.21 D) was significantly less than in the 300 lux control group (-9.73 ± 0.96 D; p = 0.022). However, compared to the 300 lux control group, 2 h periods of 10 000 lux did not produce significant effects on refraction when presented either in the morning (-9.98 ± 0.85; p = 1.00), midday (-8.00 ± 1.26; p = 0.80), or evening (-13.14 ± 1.16 D; p = 0.20), although significantly less myopia was induced in the midday group compared to the evening group (p = 0.018)." **In other words, continuous light exposure is most effective.**

Somehow in contrast to the results above experiments with chicken were summarized by Lan et al.[574]: "exposure to **continuous bright light for 1 or 2 hours** every day had no significant protective effect against deprivation myopia. Inhibition of myopia became significant **after 5 hours of bright light** exposure but extending the duration to **10 hours did** not offer an additional benefit. In comparison, **repeated cycles of 1:1 or 7:7 minutes of bright light** enhanced the protective effect against myopia and could fully suppress its development."

Light was found to increase (among others) **dopamine levels**[324, 575]. This fact matches with the statements in section 3.3.1. Moreover, this effect of light on the dopamine level can explain the positive effect of outdoor activities[576].

Norton TT el al. stated[370]: "We propose a model in which the ambient illuminance levels pro-duce a continuum of effects on normal refractive development and the response to myo-piagenic stimuli such that **low light levels favor myopia development and elevated lev-els are protective**. Among possible mechanisms, **elevation of retinal dopamine activity seems the most likely."**

Norton TT summarized[577]: Human studies have provided strong evidence that exposure to time outdoors is protective against the onset of myopia. A causal factor may be that the light levels outdoors (30,000-130,000 lux) are much higher than light levels indoors (typically less than 500 lux). Studies using animal models have found that normal animals exposed to low illuminance levels (50 lux) can develop myopia. The myopia and axial elongation, produced in animals by monocular form deprivation, is reduced by light levels in the 15,000 to 25,000 range. Myopia induced with a negative-power lens seems less affected, perhaps because the lens provides a

powerful target for the emmetropization mechanism. Animal studies suggest that raising the light levels may have their effect by increasing retinal dopamine activity, probably via the D2 receptor pathway, altering gene expression in the retina and reducing the signals that produce axial elongation."

A **mathematical model** by which the appearance of emmetropization (i.e. eye growth to achieve emmetropia) and myopia was quantitatively explained by the interaction between accommodation, vergence and optical blur[395] was extended to include the effect of the level of illumination. Result: **bad light increases the development and progression of myopia, especially of late onset myopia**[464].

Depth of focus has an impact on image acuity as Atchison et al. stated[578]: "For uncorrected myopes of 3.0 D or less, visual acuity was nearly as good with a 1-mm pupil as for corrected myopes". Therefore, a steady opening of the pupil above average might trigger a feedback circle in case of already existing imaging deficiencies, i.e. promote myopia.

In other words, a good illumination causes a good depth of focus (like at a camera), which reduces a potential blur of the image, which might avoid myopia development by a reduced image quality.

For dilated pupils (which are accompanying low levels of illumination) **increased spherical aberration** and decreased optical quality was measured[579], as the peripheral areas of the lens do not show the features of a perfect optical system (see section 3.3.9 about aberration, and section 3.3.5 about aberration and emmetropization).

This matches with the results published by Buehren et al. They found that **myopes showed more aberrations than emmetropes, and these differences were increased after 2 hours of reading**. They concluded[427]: "The differences between the groups are primarily due to changes in the corneal wavefront associated with a narrower lid aperture during reading for the myopes. These differences are enhanced by longer periods spent reading, larger pupils and consequently **low light levels**."

Notes:

*Corresponding with this fact, the **individual relation of the pupil size per level of illumination** may have an impact in both directions – too large and too small might be both negative:*

- *A **below** average pupil size results in a low level of illumination on the retina, with the mentioned negative effects.*
- *An **above** average pupil size results in a degraded depth of focus, with the mentioned negative effects.*

To some extent the illumination level has an impact on the important issue of the **vergence** (see section 3.5.3):

It was stated by Owens et al. [580]: "... convergence is a more important distance cue than accommodation under low illumination..." and by Kersten et al. [581]: "Accommodation to a dim target corresponded closely to the convergence accommodation".

Note:
*It can be concluded that under **low light** a convergence problem like esophoria can have a negative impact on accommodation, e.g. **create over-accommodation.***

Vannas et al. stated[582]: "...there was a trend towards a higher prevalence of myopia among conscripts living above the Arctic Circle, consistent with the hypothesis that **ambient lighting might influence refractive development**. Other novel associations with myopia were the **decreased use of sunglasses and brown iris color**."

Notes:
Several explanations for these results of "a higher prevalence of myopia among conscripts living above the Arctic Circle" could be offered: The lack of complete darkness during summer, the lack of sufficient light during winter, and a lack of vitamin D caused by the lack of light during winter (see section 3.24.3).

The association between myopia and a decreased use of sunglasses could be explained, e.g., by temperature effects (see section 3.16).

Norton and Siegwart[385] proposed a model according to which the positive effect of time spent outdoors (see section 0) could be explained by the elevated illumination level outdoors and its activation of dopamineric pathways.

Lan W et al. summarized their results[583] "Bright light stimulates choroidal thickening in chickens, although the response is smaller than with experimentally imposed myopic defocus, and it occurs with some time delay. It nevertheless suggests that choroidal thickening is also involved in myopia inhibition by bright light."

Read SA et al. reported[584]: "Myopic children (n = 41, mean daily light exposure **915 ± 519 lx**) exhibited significantly lower average light exposure compared to 41 age- and gender-matched emmetropic children (**1272 ± 625 lx**, $p < 0.01$). The amount of **daily time spent in bright light conditions (>1000 lx)** was also significantly greater in **emmetropes (127 ± 51 minutes) compared to myopes (91 ± 44 minutes**, $p < 0.001$). No significant differences were found between the average daily physical activity levels of myopes and emmetropes ($p > 0.05$).

In somewhat more detail, Read SA reported[585]: "Categorized according to their objectively measured average daily light exposure and adjusting for potential confounders (age, sex, baseline axial length, parental myopia, nearwork, and physical activity), children experiencing low average daily light exposure (mean daily light exposure: **459 ± 117 lux, annual eye growth: 0.13 mm/y**) exhibited significantly greater eye growth than children experiencing moderate (**842 ±**

109 lux, 0.060 mm/y), and high (**1455 ± 317 lux, 0.065 mm/y**) average daily light exposure levels."

CM Jung et al. reported "Bright light exposure significantly reduced plasma cortisol levels at both circadian phases studied …".

About the impact of cortisol on myopia see section3.19.1.

W Lan et al. reported[586] results about experiments with chicks: " Compared with the reference group, exposure to continuous bright light for 1 or 2 hours every day had no significant protective effect against deprivation myopia. Inhibition of myopia became significant after 5 hours of bright light exposure but extending the duration to 10 hours did not offer an additional benefit. **In comparison, repeated cycles of 1:1 or 7:7 minutes of bright light enhanced the protective effect against myopia and could fully suppress its development.**

Conclusions: The protective effect of bright light depends on the exposure duration and, to the intermittent form, the frequency cycle. Compared to the saturation effect of continuous bright light, low frequency cycles of bright light (1:1 min) provided the strongest inhibition effect. **However**, our quantitative results probably might not be directly translated into humans, but rather need further amendments in clinical studies."

Ulaganathan et al. reported results of **associations with light exposure and longitudinal axial length and choroid changes**[587]: "In summary, diurnal variations in AL [Axial Length] were higher in amplitude in myopes compared to emmetropes and were also associated with longitudinal changes in AL. These findings suggest that diurnal variations may be associated with longer-term axial eye growth. **Time spent in bright light also significantly influenced the amplitude of daily AL variations, with more time exposed to bright light associated with a smaller amplitude of diurnal AL change**. **Choroidal thickness exhibited an inverse association with the AL changes, implying a potential role for the choroid in eye growth.**"

Li et al. reported[180]: Results: "**WD [working distance] and LI [light intensity] were positively associated with SER [spherical equivalent refraction]**. … When WD and LI were split up, the detrimental threshold was approximately 40 cm for WD and **6300 lux for LI.**"

Goffart et al. found[487] by experiments with monkeys that **saccade movements were significantly different depending on the level of illumination.**

Landis et al. reported[588] "We found that mice exposed to either scotopic [1.6×10^{-3} candela/m^2],or photopic [4.7×10^{3} cd/m^2] lighting developed significantly less severe myopic refractive shifts … than mice exposed to mesopic [1.6×10^{1} cd/m^2] lighting … **DA [dopamine] activity, was highest under photopic light regardless of lens defocus treatment.**

Note:
It is surprising that the lowest level of illumination was more efficient against myopia than the medium level of illumination.

In section 3.3.11 the effect of peripheral defocus, which is related to image quality and therefore to level of illumination is discussed.

Summary:

Good illumination is highly recommended especially for near work – as Feldkaemper et al. stated[331]: "Because the experiments show that the eye becomes more sensitive to image degradation at low light, the human eye may also be more prone to **develop myopia if the light levels are low during extended periods of near work**." And Ashby et al. confirmed[566]: "**… results, in conjunction with recent epidemiologic findings, suggest that daily exposure to high light levels may have a protective effect against the development of school-age myopia in children.**"

Notes:
This argument is very convincing, as every photographer knows that high levels of illumination results in sharper pictures with a higher contrast. Moreover, reduced image quality was made responsible for myopia (see section 3.3), and therefore low levels of illumination will favor myopia.

Apparently, our grandmothers were right, when they warned:

"kids, don't read at bad light!"

Another conclusion is that people should wear sunglasses only for very bright light and not to follow a fashion trend only.

Additionally it has to be noted that in the past the majority of people **worked outdoors**, where in general a by far higher level of illumination exists.

Some recommended levels of illumination for comparison[589] are shown in Table 8:

Condition	lux	ftcd
Sunlight	107,527	10,000
Full daylight	10,752	1000
Normal office work	500	
Detailed drawing work	1,500 – 2,000	
Prolonged and exact visual tasks	5,000 – 10,000	

Table 8 Typical levels of illumination

For the related issues of

- **outdoor activities** see section 3.8
- **dopamine** (which is sunshine dependent) and myopia see section 3.3.3**.**

3.14.2 Color of Illumination – Wavelength of the Light

3.14.2.1 Individual Results

As light of longer wavelength (red) is dispersed less than light of shorter wavelength (blue), the exact image of a multicolor (e.g. white) object exists in different planes, e.g. the exact image on the retina exists for one wavelength (color) only. For the **other wavelength the image on the retina is not perfectly focused** (chromatic aberration; this effect is often used by the optometrist to check for overcorrection). Corresponding with this fact is that persons who wore blue filters showed initially some degree of myopia[590].

See section 3.3.10 for an image about chromatic aberration.

Other authors came to the same conclusion – i.e. a recommendation to eliminate infrared light, which is close to visible light – via a completely different model. They concluded from experiments that the **hyperthermia, which is caused by the infrared light**, increases the activity of enzymes, which causes a **loss of the spatial structure of hyaluronic acid and collagen biomolecules.**[591]

In line with these results, Long Q et al. found[592] "Compared with the guinea pigs raised in normal conditions, the **guinea pigs raised in long-wavelength and mixed lights were more myopic and also showed longer vitreous chamber depth** at 2, 4, and 6 weeks."

The progression of myopia of school kids is **slower during summer holidays**[150, 151, 152]. This might be attributed to the longer time spent outdoors, where the wavelength of the light is shorter that indoors.

Neitz J and Neitz N summarized their experiments with colored lens filters which exposed the eye mainly to the **blue, shortwave light component** which dominates outdoors[593]: "**Eyes wearing the experimental treatment lens grew 10 times slower then eyes wearing the control lens**."

Long Q et al. reported[594]: " Compared with the guinea pigs raised in normal conditions, the guinea pigs **raised in long-wavelength and mixed lights were more myopic** and also showed longer vitreous chamber depth at 2, 4, and 6 weeks."

Hathaway reported[595], that elementary students exposed to full spectrum fluorescent lighting with ultraviolet light supplements showed in general better growth, attendance, achievement and development than the other students. High-pressure sodium lamps with their warm lighting gave the worst results.

Cowan et al. reported[596], "This finding is consistent with our hypothesis that **blue light function may have utility as an assay of CNS [central nervous system] DA [dopamine] tone**." For the impact of dopamine on myopia, see section 3.3.3.

Quian et at.[597] summarized previous results of various authors: "Relative to the broadband white light (BL), postnatal guinea pigs **develop myopia in a monochromic middle-wavelength light** (ML, 530 nm) environment and **develop hyperopia in a monochromic short-wavelength light** (SL, 430 nm) environment." They found additionally by experiments with guinea pigs that a recuperation from the exposure to SL or ML light can take very long.

Jiang et al. reported[598]: "**Blue light inhibited axial eye growth, even when animals** [guinea pigs] **were reared with negative lenses.**"

Foulds et al. reported about experiments with chicks[599]: "**Red light** [90% red, 10% yellow-green] **induced progressive myopia** (mean refraction ± SD at 28 days, -2.83 ± 0.25 diopters [D]). **Progressive hyperopia was induced by blue light** [85% blue, 15% green] (mean refraction at 28 days, +4.55 ± 0.21 D). …

Myopia induced by 21 days of red light (-2.21 ± 0.21 D) **was reversed to hyperopia** (+2.50 ± 0.29 D) **by subsequent 21 days of blue light.**

Hyperopia induced by 21 days of blue light (+4.21 ± 0.19 D) **was reversed to myopia** (-1.23 ± 0.12 D) **by 21 days of red light."**

Torii H et al. summarized their experiments[600], "that high myopic patients with the non-**VL [violet light]** transmitting pIOLs [phakic intraocular lens] implanted are almost two times more myopic in the change of refraction and four times longer in the change of axial length, compared to those implanted with the VL transmitting pIOLs. This result indicated that the VL transmitting pIOL suppressed myopia progression and axial length elongation compared with the non-VL transmitting one. In conclusion, our study **showed the VL possibly has an anti-myopia effect for human adults with high myopia**."

Schaeffel summarized[532] work by Tori and Wang: Light of short wavelength might prevent myopia progression and increase the release of dopamine.

This matches with the earlier observation that he mechanical stability of corneas was improved by treatment with vitamin B2 (riboflavin) **and UV irradiation**, **which introduced additional cross-links** (see sections 3.24.15and 4.2.13).

The mechanical stability of corneas was improved by treatment with vitamin B2 (riboflavin) **and UV irradiation**, which introduced additional cross-links (see sections 3.24.15and 4.2.13).

Ostrin summarized work by various authors[972]: "Results showed that guinea pigs **raised in green light had significantly higher levels of pineal gland melatonin, whereas guinea pigs raised in blue light had decreased melatonin, presumably as a result of** increased ipRGC-i**nduced melatonin suppression**. Additionally, **guinea pigs raised in green light developed more myopic refractive errors than those raised in blue light**. The authors speculated that the increased melatonin experienced by green light potentially induced alterations in retinal growth factors or changes in ocular circadian rhythms that ultimately led to increased eye growth.

An anecdotal experience of a reader of this Manual[601]: "Nonetheless, in my pseudo-research, with Blue Light and Red Light, I noted no differences between before and after 40 hours when using 450nm light. (Could read at 7 inches, before and after) and a **major decline after 13 hrs of 660nm red light (Could read at 7 inches before, 5 inches after**)".

Rucker et al. reported[602]: "We alternately exposed one eye of each chick to a … simulating myopic defocus ("MY defocus": image focused in front of retina; hence, red contrast higher than blue) and the other eye to a grating of the same spatial frequency simulating hyperopic defocus ("HY defocus": blue contrast higher than red). … The eyes compensated in the appropriate directions: **The choroids of the eyes exposed to the HY simulation showed significantly more thinning (less thickening) over the course of the experiment than the choroids of the eyes exposed to the MY simulation … The rate of scleral GAG [glycosaminoglycans] synthesis in the eye exposed to the HY simulation was significantly greater than in the eye exposed to the MY simulation.**"

Rucker et al. summarized[603]: "Despite the older age range [39.9 ± 8.9 years], **a greater reduction in eye growth (0.29 mm) after 5 years was found in the UV-transmitting group** [group wearing UV-transmitting lenses]. … Moreover, any benefit of exposing the eye to UV light is likely to be outweighed by the greater risk of photo-oxidation, corneal keratitis, and lenticular opacities.

Note:
Obviously this positive effect can be attributed to improved cross-linking of collagen (see section 3.24.15).

Yu et al. reported[604]: "… guinea pigs **exposed to SL [short wavelength light, 440 nm, 500 Lux] were less myopic than to WL [white light, 580 Lux] (2.06 ± 1.69D vs. -1.00 ± 1.88D), accompanied with shorter AL [axial length] and less retinal RA** [retinoic acid, which is known to increase myopia]. SL reduced retinal RA even after exogenous RA supplementation and decelerated LIM [lens induced myopia] compared to WL

Dfuji et al. reported[605] a case in which blue **light transmitting glasses and engagemnent in two hours of outdoor activities** resulted for a boy with high myopia and anisometropic amblyopia **resulted in reduced axial length and thickened choroid**.

Norton et al. reported[606]: "… data support the conclusion that **the emmetropization mechanism cannot maintain emmetropia in narrowband lighting**". The reason was said to be a lack of longitudinal chromatic aberrations.

Najjar et al. reported[607] about experiments with chicks: "this study, we show that exposure to moderate intensities [about 230 lux] of **blue-enriched white light [9700 K] can slow axial elongation, reduce aberrant ocular structural changes and accelerate recovery from increased axial ocular growth in a chicken model of form-deprivation myopia** [as compared to light with 3900 K]."

Mori et al. reported[608]: "The mean change in axial length in the VL glasses group [violet light-transmitting eyeglasses (VL glasses) which can transmit violet light 360–400 nm in wavelength], was significantly smaller than in the placebo glasses group **when time for near-work was less than 180 min** and when the subjects were limited to those who had never used eyeglasses before this trial … **The suppressive rate for axial elongation in the VL glasses group was 21.4% for two years**."

Thakur et al- reported[609]: "…adults were **exposed to blue (460 nm), green (521 nm), red (623 nm), and white light conditions** for 1-hour each on 4 separate experimental sessions conducted on 4 different days. In each light condition, hyperopic defocus [by a minus lens of 3D] was induced to the right eye with the fellow eye experiencing no defocus. … **Axial length increased from baseline after red light** (mean difference ± standard error in the defocussed eye and non-defocussed eye = 11.2 ± 2 µm and 6.4 ± 2.3 µm, … respectively) **and green light exposure** (9.2 ± 3 µm and 7.0 ± 2.5 µm …) **with a significant decrease in choroidal thickness** … after 1-hour of exposure. **Blue light exposure resulted in a reduction in axial length in both the eyes** (−8.0 ± 3 µm, $P < 0.001$ in the defocused eye and −6.0 ± 3 µm, $P = 0.11$ in the non-defocused eye) with **no significant changes in the choroidal thickness**."

Notes:

*Obviously the **color of the light alone**, i.e. without any significant accommodation and focusing effort can lead to increased axial length and decreased choroidal thickness and therefore myopia or its progression.*

*All this supports the results of the positive effect of **outdoor acticities** where cold light is dominating (see section 3.10*

Additionally, This could lead to the conclusion that near work should be done in cold, - i.e. most likely cold fluorescent or LED-light, what is discussed in more detail in section 3.14.2.4. See also section 3.16 about the impact of the temperature.

In section 1.11 it was already mentioned:

If you can see numbers or letters on a distant chart clearer and with more contrast when looking through a red glass of foil than through a green one, there is undercorrection.

If the contrast is better for the green pichture, there is overcorrection.

Therefore, a cold-color light results in less accommodative stress for the eye than a warm-color light.

Moreover, there are reports about positive results of **treating patients with more general visual disorders** by the effect of an illumination with specific colors[610].

See also the related section 3.24.15.1 about the **use of Riboflavin and UV-light for enforcing the sclera**.

3.14.2.2 The Effect of Broadband Illumination

It was concluded once that the eye does **not use this chromatic effect to detect the sign of a defocus** (too near / too far)[97], i.e. that chromatic aberration is not essential for emmetropization. This is in contrast to a statement by Schmid et al. [611]: "...data hint that **chromatic aberration may have some role as a cue to defocus in emmetropization**."

An experiment by Kroger et al. [612] about the accommodative response during near work showed, however that "The refractive state was largely independent of the color temperature of the illumination light (white paper) and the color of commercially available papers (white illumination). Selective **elimination of long wavelengths, however, significantly reduced the accommodation stimulus by about 0.5 diopters**." These authors "suggest that the visual system primarily uses long wavelengths, if available, during reading tasks."

Yoon et al. reported[613] about experiments with chicks: " In **broadband light, longitudinal chromatic aberration (LCA) provides emmetropization signals from both wavelength defocus and the resulting chromatic cues. Indoor illuminants vary in their spectral output, potentially limiting the signals from LCA**. … We conclude that axial growth and refraction were dependent on the lighting condition in a manner predicted by wavelength defocus signals arising from LCA. … **Broad spectrum artificial illuminants with a brighter blue component slow axial growth.**"

3.14.2.3 Melanopsin and Neuropsin

Chakraborty et al. reported[614]: "Melanopsin-expressing retinal ganglion cells (mRGCs), which detect light, are important for visual function, and **have connections with retinal dopamine cells**. … Collectively our findings show that disruption of retinal melanopsin signaling alters the rate and magnitude of normal refractive development, **yields greater susceptibility to form-deprivation myopia, and changes dopamine signaling**."

Wikipedia summarized[615] " Melanopsin photoreceptors are sensitive to a range of wavelengths and **reach peak light absorption at blue light wavelengths around 480 nanometers**."

Jiang reported[616]: "Here, we show that **violet light prevents lens defocus–induced myopia in mice.** This violet light effect was dependent on both time of day and retinal expression of the violet light sensitive atypical opsin, neuropsin (OPN5). These findings identify Opn5-expressing retinal ganglion cells as crucial for emmetropization in mice and suggest a strategy for myopia prevention in humans."

Note:
These are some more hints at the positive effect of blue light, which is dominating the outdoor illumination, which was shown to be very important to prevent myopia and its progression.

3.14.2.4 Blue Light Emitted from Electronic Screens: What are the Risks?

Zhi-Chun Zhao et al. wrote[617]: "spectrum, short-wave blue light with wavelength between 415 nm and 455 nm is closely related to eye light damage. **This high energy blue light passes through the cornea and lens to the retina causing diseases such as dry eye, cataract, age-related macular degeneration, even stimulating the brain, inhibiting melatonin secretion, and enhancing adrenocortical hormone production, which will destroy the hormonal balance and directly affect sleep quality**."

On the other hand, as Schaeffel stated[618], **"The amount of blue light you're exposed to when you go outside is so much greater than anything you'll get from a computer screen.**

Note:
To prevent sleep disturbances the use of devices emitting blue light should be avoided in the late evening, as melatonin will be reduced. *See sections 3.14.4 and 3.25.4.3 about melatonin.*

3.14.2.5 LLLT – Low-Level Laser Therapy

LLLT uses low levels of red or near infrared light. Its wavelength ranges from 600 nm to 1100 nm, and its output can reach 700 mW.

Xiong et al. reported[619]: "Changes in axial length (AL) were 0.23 ± 0.06 mm for children wearing spectacles, 0.06 ± 0.15 mm for children wearing OK [orthokeratology] lens, and - 0.06 ± 0.15 mm for children treated with LLLT for 6 months. Changes in subfoveal choroidal thickness (SFChT) observed at the 6-month examination were -16.84 ± 7.85 µm, 14.98 ± 22.50 µm, and 35.30 ± 31.75 µm for the control group, OK group, and LLLT group, respectively."

This means LLLT not only prevented progression of myopia, but even resulted in a slight reduction of existing myopia.

They **explained the positive effect of LLLT** by its effect on the nitric oxide system, the decrease of oxidative stress and reduction of inflammatory cytokines.

Ghamdi et al. reviewed publications about LLLT saying[620], "… many articles report that it produces higher rates of ATP, RNA, and DNA synthesis in stem cells and other cell lines. Thus, **LLLT improves the proliferation of the cells** without causing any cytotoxic effects."

Jiang et al. reported about his results with 246 children 117 in the RLRL (repeated low-level red-light) and 129 in the control group[621]: "The RLRL treatment was provided by a desktop light therapy device [a type which is commonly used for the treatment of amblyopia] which emits red light of 650 nm in wavelength, at an illuminance level of approximately 1600 lux and a power of 0.29 mW for a 4-mm pupil (Class I Classification), and was administered at home under supervision of parents, 3 minutes per session, twice per day with a minimum interval of 4-hours, five days per week. … Adjusted **12-month axial elongation and SER [spherical equivalent refraction] progression were 0.13 mm and -0.20 D (95% CI: -0.29 to -0.11) for RLRL treatment, 0.38 mm (95% CI: 0.34 to 0.42) and -0.79 D (95%CI, -0.88 to -0.69) for SVS [control group]**. … In our study, we demonstrate that RLRL treatment was able to achieve greater than 0.05 mm axial length shortening in 70.1% of the participants at 1-month and 31.6% at 12-months"

LLLT was found to be helpful for various eye problems like macular degeneration as well[622, 623].

Note:

This positive effect appears to be surprising, as red light during normal focusing was more likely having the opposite effect as mentioned above. The difference is that LLLT is appied for short times only and directly into the eyes, and laser light is technically different from other light (The light from a laser is said to be coherent, which means the wavelengths of the laser light are in phase in space and time).

3.14.3 Contrast

AC Aleman et al. reported[624]: " subjects, we found that t**he choroid**, the heavily perfused layer behind the retina in the eye, **becomes about 16 µm thinner in only one hour when subjects read black text on white background but about 10 µm thicker when they read white text from black background.** Studies both in animal models and in humans have shown that thinner choroids are associated with myopia development and thicker choroids with myopia inhibition. **Therefore, reading white text from a black screen or tablet may be a way to inhibit myopia, while conventional black text on white background may stimulate myopia."**

Hinterlong et al. reported[625]: "**Multimedia exposure under brighter classroom conditions may contribute to the myopia incidence** in schoolchildren. Teaching with digital projection technology is increasingly prevalent. This may increase children's odds of developing myopia, which has far-reaching and lifelong deleterious effects."

Contrast is an issue in section 3.3 as well.

3.14.4 Day- and Night-Rhythm

Investigations have shown that growing eyes of chickens **elongate during the day and shorten during the night,** following the changes of the IOP with some delay**.**[626] Liu JH reported[627]: "However, **the magnitude of this IOP elevation at night was significantly less in the myopia group**. In the sleep period, IOP was less in the myopia group than in the control group…There is a 24-hour rhythm of supine IOP in the myopic group, but **the phase timing is different** from that in the control subjects."

In experiments with mice it was found, that **extended periods of light exposure result in a trend towards myopia, increase in axial length and retina thinning[628].**

Chakraborty R et al. reported[629]: "**AL [Axial Length] underwent significant diurnal variation** that was consistently observed across the 2 measurement days. The longest AL was typically observed at the second measurement session (mean time, 12:26) and the shortest AL at the final session of each day (mean time, 21:06)." and "**A positive association was found between the variations of AL and IOP [Intra Ocular Pressure] and AL and VCD [Vitreous Chamber length] and a negative association between AL and choroidal thickness".**

There is, however, a rhythm in axial length and choroidal thickness even in constant darkness[630], apparently due to the circadian rhythm (i.e. night-/day-rhythm), which is triggering numerous biochemical processes. Rada summarized[360]: "**In eyes that are developing myopia, the growth rhythm breaks down**."

Another effect of the day- and night-rhythm was reported by Ohngemach[336] in a paper about the dopamine metabolism: "**Intermittent periods of normal vision inhibited deprivation myopia more if they occurred in the evening than in the morning**."

Yun et al. generalized[631]: "We hypothesize that declining dynamic range and variation of environmental cues may contribute to health dysfunctions, and that judicious expansion of biologic dynamic ranges may be beneficial... Daytime sheltering, optical shading, and nighttime use of artificial light may reduce circadian luminal variation. The resulting melatonin alterations may contribute to systemic dysfunctions."

The result of a study in 1999 was that **night-lights** increase substantially the probability of myopia for kids[632]: the probability was found to be increased more than three-fold for night-lights and more than five-fold for full light in the sleeping room.

Later other studies came to different results[633, 634], and the dispute between the researchers is still open[635], focusing on the question whether the studies were properly and neutrally designed. It looks like that the brightness of the dimmed night light might be an essential parameter[636].

It was proposed to use red night-lights instead of a white one, because it was said that the red one does not have an impact on melatonin production.[637]

The night-light issue cannot be judged here, but there are some related observations, which offer several potential explanations:

Illumination has a high impact on melatonin production. Glickman et al. stated[638]: "Less than 1 Lux of monochromatic light elicited a significant suppression of nocturnal melatonin", and melatonin and dopamine block each other[375]. While some researchers found that direct injections of melatonin have no impact on myopia[639], Rada et al. reported the opposite[640]: "Systemic administration of melatonin resulted in significant changes in anterior chamber depth, vitreous chamber depth, and choroidal thickness of form-deprived and/or control eyes." Other researchers like Kusakari[47] believe in an "intimate relation between the development of myopia and the day-night rhythm of melatonin in the pineal and the retina". And Ohngemach et al. stated[336] that "… results show that the pineal gland [which produces melatonin] has a surprisingly large influence on both the retinal dopamine receptor gene transcription and dopamine release". Additionally, eyes were found to grow in length only during the day[47], and myopia probably increases with shortened sleep[161]. The amacrine cells in the retina were found to play a key role in the control of the dopamine signaling, and these cells are influenced by melatonin metabolism[373].

Consequently, a night-light can disturb the regular day-night rhythm with the respective results.

For the impact of dopamine on myopia, see section 3.3.3

Furthermore, oxidative stress appears to be present in myopic eyes, combined with a lack of the antioxidant gluathione peroxidase – and melatonin (which is produced by the pineal gland) was found to stimulate production of gluathione peroxidase[641].

A night-light is normally kept on, if there is a serious **sleeping disorder**. This disorder can be caused by a disturbed dopamine/melatonin balance, or by a lot of other biochemical or psychological disturbances. In this case, the night-light is not the reason for myopia, but a symptom of a disorder, which leads to myopia via other mechanisms.

Just one example: Vitamin **B6 deficiency can cause insomnia**[642], and vitamin **B6 is as well a key substance for connective tissue integrity**[643].

This means that switching off the night-light does not necessarily stop the development of myopia. The underlying reason for the sleeping disorder needs to be addressed.

A test with students had the result that a reduced **daily exposure to darkness** resulted in increased probability of myopia progression[644], while other influences like amount of near work were controlled.

Note:
This result could be caused by a change of the illumination-triggered metabolism of melatonin.

There appears to be **an effect of night light other than on the optical sytem**[645]:Hamsters which were exposed to 5 Lux at night showed **symptoms of depression and a modified brain structure**. Their brains had a "significantly reduced density of dendritic spines – hairlike growths of brain cells, which are used to send chemical messages from one cell to another."

Stone RA et al. summarized[646]: "Experimental myopia induced by the wearing of a concave spectacle lens **alters the retinal expression of a significant proportion of intrinsic circadian clock genes, as well as genes encoding a melatonin receptor and the photopigment melanopsin**. Together this evidence suggests a hypothesis that the retinal clock and intrinsic retinal circadian rhythms may be fundamental to the mechanism(s) regulating refractive development, and that disruptions in circadian signals may produce refractive errors."

·Ayaki M et al reported[647] : "… **children disclosed that the high myopia groups had the shortest sleep duration, worst subjective sleep scores, and latest bedtime.**" They question whether this sleep disorder is caused by myopic retinal complications or the poor unaided vision.

Chakraborty R et al. reported[648]: Results: Myopes (22:19 ± 1.8 hrs) **exhibited a dim light melatonin onset phase-delay of 1 hr 12 min compared to emmetropes** (21:07 ± 1.4 hrs). Urinary aMT6s melatonin levels were significantly lower among myopes (29.17 ± 18.67) than emmetropes (42.51 ± 23.97). Myopes also had a significant delay in sleep onset, greater sleep onset latency, shorter sleep duration and more evening-type diurnal preference than emmetropes,"

Liu et al. summarized results of a study with 6295 children aged 6 to 9 years[649]: "Our results suggest that **'sleeping late' is a risk factor for myopia prevalence** at baseline (**odds ratio [OR] = 1.55**). 2-year myopia incidence (**odds ratio [OR] = 1.44**) and progression over 24 months, after adjusting for residency area, age, gender, sleep duration, and time spent outdoors."

Hussain et al. reported[650]: "Myopes were found to have significantly lower concentration of serum dopamine … myopes showed significantly **lower serum melatonin** concentration … Myopes exhibited **lower concentration of tear dopamine** … myopes showed significantly **lower tear melatonin concentration**. … **The observed changes in the decreased concentration of Dopamine and Melatonin among young adult myopes and its association with refraction indicates the role of altered circadian rhythm in the human myopia mechanism**."

3.14.5 Flickering Light and Flashing Light

Flickering light (flickering frequency around 10 times per second) can

stimulate the release of dopamine and reduce the degree of artificially induced myopia, and

increase choroidal blood flow (see section 3.3.1). The retinal blood vessel dilation is increased[651, 652], but this retinal vessel dilation by flickering light is reduced if the level of nitric oxide (NO) is reduced[653] (see section 3.17 about myopia and blood circulation, and section 3.18.7 about myopia and NO).

Additionally, this response to flickering light is reduced in patients with **elevated blood sugar**[651] **or with diabetes**[654] (for the impact of blood sugar or hyperglycemia on myopia see section 3.24.1)

Czepita et al. claimed[655] "It was found that the **use of fluorescent lamps was associated with an increase in the occurrence of hyperopia** [i.e. long-sightedness]."

On the other hand, **flashing light** (flashing frequency 15 times per minute, 2 seconds light on and 2 seconds light off) was found to promote myopia and eye growth[656]. In experiments with guinea pigs a frequency of 0.5 Hz caused the largest myopic shift compared with frequencies of 5, 1, 0,25 and 0.1 Hz[657].

Note:
Is there a causal connection between the effects of flickering light and saccades, as both have a similar magnitude of their frequencies (see section 3.6 about saccades)?

3.15 Vision Training / Vision Therapy / Behavioral Optometry

Vision training[658, 659, 660, 782, 661, 662] (also called **vision therapy, visual training, behavioral optometry, developmental optometry**) is a concept to improve the eyesight by specific **training of all the components and functions of the eye and the vision. This includes** the lens, the ciliary muscles, the extraocular muscles, and the also the brain, which is involved in the coordination of seeing and the corresponding signal processing.

Behavioral optometry[663] is specifically based on the experience that vision problems be the cause of significant behavioral and learning problems and that a solution of the vision problem can directly solve these problems. Skeffington stated[315]: "**What we are considering is a *visual problem*, which is different from an *eye problem***".

Vision training is related to the Bates-Method (see section 3.2.2), but goes far beyond, incorporating additional issues like Convergence (see section 3.5), saccades and focusing (see section 3.6), mechanics (see section 3.7), illumination (see section 3.8) and mental issues (see section 3.19).

Vision training uses many devices like lenses, prisms and computer software, but there are also exercises for which no specific tools are necessary.

It is emphasized that the exercises have to be specifically tailored to the specific problem of the individual patient, which means they need to be based on a professional eye examination. The person who is directing the vision training is normally a professional optometrist.

Note:
The success of this method depends highly on the skill and experience of the supervising optometrist. Care should be taken to find an optometrist who has in fact a strong professional overall-background in eye care and who is not just a self-made follower of some vision-training concepts.

3.16 Temperature

It was mentioned in section 3.14.1 that an **elevated temperature** of the eye, caused by illumination, has been **suggested by Trichtel as a cause for myopia**. He summarized experiences, that feverish sicknesses of children were often followed by the onset of myopia[7]. The suspected mechanism was the fact that accelerated biochemical reactions degrade the connective tissue of the sclera[664]. Numerous reports in the literature show that e.g. the activity of collagenase, an enzyme that degrades collagen, can be increased substantially by inflammations and related elevated temperatures. Additionally it was reported that the strength of connective tissue is generally rather temperature dependent.

It is hardly questionable that an elevated temperature is damaging the structure of the sclera, resulting in myopia[591, 665, 666].

The temperature of the eye can be elevated by various circumstances:

Excessive illumination was claimed to increase the temperature of the retina (see theory outlined in section 3.14.1).

It was shown that **light with long wavelength** could be expected to be harmful for myopia by raising the temperature (this increases the activity of enzymes, which causes a loss of the spatial structure of hyaluronic acid and collagen biomolecules, see section 3.14.2).

Note:
This gives a reason for using "cold" light bulbs, see section 3.16, Color of Illumination.

Near work was shown to increase the temperature of the eyeball[173].

Note:
The substantial forces applied during accommodation and vergence (see section 3.7) could explain this temperature rise.

Stress, like during examinations, was found to elevate body temperature: the higher the scores in the examination, the higher the temperature difference between examination and no-examination[667].

Feverish sicknesses[668], or generally an activated immune system, are increasing overall body temperature.

Note:
*Maybe there is an **interaction between temperature and blood circulation** (see section 3.17) – poor blood circulation may reduce the transfer of the heat generated during the hard work of accommodation.*
***Melatonin** was found to **decrease the body temperature**[669, 670] and **myopes have significantly higher serum melatonin than non-myopes**[671, 672] (which is, however in contrast to results reorted in 3.14.4), possibly the eye reacts in this sequence:*

Accommodation stress
↓
Elevated temperature
↓
Degraded connective tissue and elevated melatonin
↓
Decreased dopamine
↓
Myopia

About the interworking between melatonin and dopamine, see section 3.25.4.3

Summary:

An elevated temperature is a candidate for causing myopia. This alone, however, gives little help to prevent it, as it is a consequence of other processes.

The fact that an **elevated temperature significantly decreases the stability of connective tissue** (i.e. of the sclera) is important in connection with the thesis that during near work substantial **mechanical forces are applied** to the eyeball – forces which act in the direction of axial myopia (see section 3.7). This mechanism also has significance in connection with **increased activities of the immune system**, which elevates the temperature, too, and which was found to be relevant for myopia (see section 3.18).

Consequence:
With the arguments discussed in section 3.9 ("Growth or Stretching and Thinning or Biochemical Thinning of the Sclera in Myopic Eyes?**") in mind it is highly recommended to avoid longer lasting near accommodation during or shortly after a feverish illness.**

3.17 Blood Circulation

It was found by Ravalico et al. [673] that "with regard to increasing axial length and refractive error a progressive **reduction in ocular pulse amplitude and pulsatile ocular blood flow** was noted".

Lam et al. stated[674]: "The pulsatile ocular blood flow was negatively correlated with axial length" (i.e. the longer the eye the lower the pulsatile ocular blood flow), and Reiner et al. stated[675] that "myopic eye growth produced from vision degradation leads to dramatic reductions in choroidal blood flow". Very specific Dimitov et al. stated[676] that "Central retinal and posterior ciliary blood velocity decreases with the increase of the degree of myopia."

There was a significantly increased **resistance** index for the blood flow in the posterior ciliary artery[677]. This **decreased blood** flow was seen in both human and animal studies.

Khatsukov found[214]: " It was found that respiration function and oxygen regime in myopia children and adolescents are 2-3 years behind those in normal children and adolescents. … 20-day interval hypoxic training in children and adolescents raised efficacy of the external respiration and circulation, normalized bioelectric activity. The majority of the patients improved their visual acuity up to complete normalization."

On the other hand, an increased blood circulation explained the success of a specific surgical treatment[678], and development of experimental (form–deprivation) myopia was suppressed by **flickering light**, which increased choroidal blood flow (and dopamine release)[2].

Some authors however, were concluding that this **reduced blood flow is a consequence, but not a reason for myopia**.

Overall, it was concluded that increased choroidal blood flow is protecting the eye from lengthening[679].

Additionally, in eyes that are recovering from artificial (form deprivation) myopia a temporally increased choroidal blood flow was observed together with an increase in choroidal thickness[680].

A severely reduced blood circulation in the retina (retinal ischemia) can severely damage retinal neurons[739].

Blood circulation supplies the tissue with oxygen. H Wu reported[681] "Collectively, these findings defined an essential role of hypoxia in scleral ECM [extracelluler matrix] remodeling and myopia development, suggesting a therapeutic approach to control myopia by ameliorating hypoxia."

E Grudzinskaia wrote[682]: "… technique which showed a lower volume of blood supplied to the retina and choroid. These observations are in line with delayed blood flow noticed in angiography. … Reduced ocular blood flow in myopia has been detected using various diagnostic techniques, and the introduction of new ones allows for more accurate measurements. ***Many researchers consistently reported lower blood flow parameters in myopic eyes regardless of the used diagnostic method. It is unclear whether this is a primary change that causes secondary thinning of ocular tissues or quite the opposite; that is, the mechanical stretching of the eye wall reduces its thickness and causes a secondary lower demand of tissues for oxygen.****"*

Wu et al. considered scleral hypoxia as a target for myopia contraol[683].

Huemer et al. wrote[684]: "Our data indicate that ***dopamine has a pronounced enhancing effect on the retinal perfusion in humans****".*

Notes:

- ***Nitric oxide*** *was found to increase blood circulation (see section 3.18.5).*
- *Even if a reduced blood circulation is not causing the onset of myopia, the decreased blood flow as a consequence of myopia can contribute to a further* ***progression*** *of myopia.*
- *The exact mechanism of reduced blood circulation in the myopic eye appears to be still open. Maybe the structural degradation of connective tissue in high myopia is responsible for this effect in a similar way, as people with problems of the connective tissue frequently appear to have a* ***low blood pressure*** *(no reports are known, however, about a correlation between low overall blood pressure and myopia).*
- *Maybe there is an interaction between blood circulation and temperature (see section 3.16) – a lack in blood circulation may reduce the transfer of the heat, which is generated during the hard work of accommodation.*

- *The insufficient supply with oxygen observed at myopes can be interpreted as an **accommodation overload, which requires higher rates of oxygen**.*

3.18 Some Specific Biochemical Issues

3.18.1 The Immune System

Some results about the significant interaction between the immune system and myopia (especially more severe myopia) are:

Antibodies to collagen were found in the serum of myopic people. However, a control group, and surprisingly the most severe group of myopes, had no such antibodies The authors draw these conclusions[685]:

- The immune response to collagen can serve as a definite indicator of pathologic changes in the sclera.
- An accumulation of collagen antibodies in the serum can be considered a normal reaction to changes in collagen structure
- The lack of collagen antibodies may be considered a prognostic factor of an unfavorable course of myopia.

Circulating immune complexes (CIC) in the serum and the anterior eye chamber were measured. Patients with complicated myopia had a highly elevated CIC level, indicating autoimmune processes being responsible for biochemical changes in the eye tissue[686].

Examination of patients with myopia has revealed disturbances of the immune system by a **decreased absolute amount of T-lymphocytes** and an **increased content of immunoglobulins** in blood serum. The shown sensitization of the body to eye tissue antigens hints at the participation of autoimmune processes in the pathogenesis of myopia. The authors conclude that an inhibition of the thymus function leads to degenerative changes in the sclera and destruction of collagenic fibers[687].

A study found that asthma and other allergies, as well as myopia, were more frequent for extremely mathematically and/or verbally excellent students (see section 3.19.2)

As mentioned in among the rate of asthma and other allergies, and myopia was substantially higher[688], which is showing a connection between myopia and **autoimmune reactions**.

Several authors found a correlation of myopia with a variety of **infectious diseases** in childhood[689].

It was described that children of mothers who suffered from **infections** during pregnancy were four times more likely than normal to become myopic before the age of 8 years[690].

Fledelius et al. stated[691]: "The elevated myopia figure of 43% among juvenile **chronic arthritis** (JCA) patients suggests an association between myopia and JCA: In lack of more precise indicators and in accordance with older literature, an explanation might be a weakening effect of chronic inflammation on scleral connective tissue".

Markwardt et al. stated[692]: "... histamine caused **contraction of the human ciliary muscle** cells in a concentration-dependent fashion." Accommodation is (generally assumed to be) performed by contraction of the ciliary muscle.

A disturbed **calcium metabolism** was found for myopes[258].

In section 3.1 it was reported that myopia is less frequent in rural areas. A potential explanation is given by the result that children in early contact with agricultural animals have less asthma and **allergies**[693].

For eyes with pathologic myopia an **elevated rate of apoptosis** (i.e. programmed cell death) **in photoreceptor cells of the retina** was observed[694]. Grodzicky et al. stated[695] that apoptosis "is a physiological process of cell death that normally occurs when cells are damaged or no longer needed." Apoptosis is **often strongly related to the immune system**, and can lead to autoimmunity.

Note:
Selenium deficiency can lead to decreased numbers of amacrine cells and of photoreceptor cells (see section 3.24.16.1).

Sheiko stated[696]: "It was established that **moderate myopia is accompanied by the functional tension of the immune systems**, namely by the secondary immunodeficiency of the cellular part…".

Wei CC et al. reported[697]: "A cohort study was conducted and confirmed that children with AC had a higher incidence and subsequent risk of myopia (hazard ratio 2.35 …) compared to those without AC [Allergic Conjunctivitis]."

A personal observation: Many people with high grade myopia are hardly ever sick, but have problems with harmless insect bites, or are suffering from asthma, all of which are all indications of an overactive immune system.

Note:
Infections both raise temperature and activate the immune system. Both of these may induce myopia, for example immune system overactivity can produce higher levels of collagenase, a collagen (i.e. connective tissue) degrading enzyme. Moreover, infections are very likely the initiators of later autoimmune diseases[698].

The related topic inflammation is discussed in section 3.18.2

3.18.2 Inflammation towards Progressive and Pathologic / Malignant Myopia

It appears to be very plausible that lower degrees of myopia are largely caused by optical effects, which lead via emmetropization to a moderate elongation of the eyeball. As Celorio et al. expressed[699]: "...[results] support the belief that **progressive myopia is a condition distinct from the more common mild degrees of myopia**."

High, progressive or even pathologic myopia, however, can be said to have – additionally – the basis in **exaggerated reactions of the immune system, i.e. in processes of inflammation.**

Very few reports about malignant myopia are available so far. The result of one of those reports was **an inverse correlation between malignant myopia and calcium content in the water as well as annual hours of sunshine**[96]. Annual hours of sunshine can serve as a measure of vitamin D supply. See section 3.24.3 for the interrelation between myopia and calcium/vitamin D.

Already in 1854 the autopsy of myopes led to the conclusion that myopia is connected with a process **of inflammation**[700].

Wei Q et al. reported[701]: "Conclusions: Proinflammatory cytokines and angiogenic growth factors were elevated in the VH [vitreous humor] of HM [high myopia, more than –6 D] patients, suggesting that an **elevated inflammatory status and higher levels of angiogenic factors are present in eyes with HM**."

Coviltir et al. summarized[702] various publications about biochemical processes taking place in myopia progression: "Many studies h**ave shown the role of the inflammatoryprocess in myopia and the expression of some proteinsrelated to changes in collagen fibers, scleral thinning, andaxial length elongation**."

Wan et al. reported[703] about experiments with animals: " We found that inhibiting inflammatory responses in the eye slowed myopia progression, whereas increasing inflammation by LPS and PGN enhanced myopia advancement. … Our results showed that **immune and inflammatory reactions would alter the progression of myopia through modulation of inflammation responses**."

Yuan et al. reported[704]: "If choroids inflammation can weaken and cause the sclera to stretch, resulting in myopia as seen in Vogt-Koyanagi-Harada disease, it is possible that persistent low-grade chronic inflammation in the retina/choroid could cause progressive stretching of the sclera and axial elongation. IL-6 and MMP-2 [both markers of inflammation] were **significantly higher in the highly myopic eyes than in the non-high myopic eyes** …(IL-6: 11.90 vs. 4.38 pg/mL … MMP-2: 13.10 vs. 8.82 ng/mL) while adjusting for age, gender, and intraocular pressure. There was a **significant positive association between levels of IL-6 and MMP-2 in aqueous humor and the axial lengths of the eye globes**."

The **positive effect of atropine was expained by a suppression of inflammation**[940] (see section 3.25.1).

Yin et al. concluded[705]: "… findings provide clinical and experimental evidence **that inflammation plays a crucial role in the development of myopia.**"

In section 3.24.3 the importance of vitamin D was discussed. Filgueiras et al. reported[706] about the connection between Vitamin D and inflammation: "The majority of the studies (five out of eight) found **association of vitamin D status with biomarkers of oxidative stress and inflammation** such as C-reactive protein (CRP), interleukin-6 **(IL-6)**, cathepsin S, vascular cell adhesion molecule-1 (VCAM-1), malondialdehyde (MDA), myeloperoxidase, 3-nitrotyrosine, and superoxide dismutase (SOD). **Vitamin D status is associated with oxidative stress and inflammation in the majority of the studies with children and adolescents**."

In section 3.25.4 the importance of dopamine was discussed. Yan et al. reported[707]: "… our results demonstrate that DA is an endogenous inhibitor of NLRP3 inflammasome activation, suggesting **that DA is a potential antiinflammatory chemical, in addition to a neurotransmitter**."

Note:
*Maybe the overload of the ciliary muscle during excessive accommodation can cause substantial ocular inflammation, as Baumert et al. reported[708]: "Prolonged unaccustomed **exercise involving muscle lengthening (eccentric) actions can result in ultrastructural muscle disruption, impaired excitation–contraction coupling, inflammation and muscle protein degradation**.*
It is astonishing that the current scientific research focuses almost entirely on image quality aspects and ignores more simple muscular related effects.

3.18.3 Oxidative Stress and Antioxidant Defense

Numerous research papers showed a correlation between higher grades of myopia and an elevated activity of oxidative processes:

Generally myopia, especially progressive myopia was correlated with damages by **oxidative processes**[709, 841].

Florence stated[710]: "The eye is an organ with intense AOS (activated oxygen species) activity, and it requires high levels of antioxidants to protect its unsaturated fatty acids".

The higher the myopia of patients with retinal detachment was, the higher was the **lipid peroxidation**, which is a free radical caused process[709]. Malondialdehyde, a breakdown product of lipid peroxidation, was found in increased levels in diabetes and higher myopia[711].

Among patients undergoing retinal detachment surgery the group of patients with more than 10 Diopter show a **significantly higher TBARS concentration**[712] in the subretinal fluid than any of the other groups studied. The TBARS (thiobarbituric acid reactive substances) concentration is an indicator for the concentration of damaging reactive oxygen-containing molecules.

For children and adolescents with progressive myopia and retinal complications a **reduced ratio between the antioxidant activity and the radical formation** in the lacrimal fluid was found.[713]

For eyes with pathologic myopia an **elevated rate of apoptosis in photoreceptor cells of the retina** was observed[694]. Grodzicky stated[695] that apoptosis, or programmed cell death "is a physiological process of cell death that normally occurs when cells are damaged or no longer needed." This process of apoptosis of retinal cells is often related to the proteases called **caspases**[714], and Nunes et al. stated[715] that "**antioxidant deficiency [in this publication a deficiency in vitamin E and selenium] significantly increased caspases-like activity**" in chick skeletal muscle cells.

Generally it was stated by Behndig et al.[716]: "If inflammatory reactions occur, **ocular tissues are at risk for damage** induced by superoxide radicals and peroxynitrite, the reaction product with nitric oxide."

Merida S et al. reported[717]: "Therefore, the **aqueous humor TAC [total antioxidant capacity] levels significantly dropped in the HM [high myopia] group. A correlation between the TAC levels and refractive error or eye axial length in the myopia patients was also found**. Depletion of TAC as an indicator of the overall capability to neutralize oxidative stress suggests excess ROS [reactive oxidant species], which may cause oxidative damage to deoxyribonucleic acid, proteins and lipids."

Wei Q et al. reported[718]: " The expression of L-PGDS, NRF-1 and GXP3, **all of which have strong antioxidative capability, decreases in the patients who have fundus chorioretinal degeneration with AL longer than 29.0 mm**."

Wimalawansa et al. summarized[719]: "**Vitamin D is one of the key controllers of systemic inflammation, oxidative stress** and mitochondrial respiratory function, and thus, the aging process in humans. In turn, molecular and cellular actions form 1,25(OH)2D slow down oxidative stress, cell and tissue damage, and the aging process. On the other hand, **hypovitaminosis D impairs mitochondrial functions, and enhances oxidative stress** and systemic inflammation. Thus, it is not surprising that hypovitaminosis D increases the incidence and severity of several age-related common diseases, such as metabolic disorders that are linked to oxidative stress.]

Fedor M et al. reported[876]: "The average serum concentration of zinc in myopic patients was significantly lower (0.865 ± 0.221 mg L^{-1}) in comparison to the control group (1.054 ± 0.174 mg L^{-1}). There was significantly higher Cu/Zn ratio in myopic patients (1.196 ± 0.452) in comparison to that in the control group (0.992 ± 0.203). The average serum concentration of selenium in the study group was significantly lower (40.23 ± 12.07 µg L^{-1}) compared with that in the control group (46.00 ± 12.25 µg L^{-1}). … **Low serum concentration of zinc and selenium in myopic children may imply an association between insufficiency of these antioxidant microelements and the development of the myopia and could be the indication for zinc and selenium supple-**

mentation in the prevention of myopia. Significantly, higher Cu/Zn ratio in the study group can suggest the relationship between myopia and oxidative stress."

3.18.4 Enzymes Glutathione, Glutathione Peroxidase, Superoxide Dismutase, G6PD

Rada summarized[360]: "Scleral remodeling, as with any tissue, is a dynamic process that involves continual synthesis and degradation of extracellular matrix." Numerous enzymes, proteinases and cytokines are involved in this process.

The body produces several enzymes for the protection of cells and tissue against other enzymes or against oxidants. An **imbalance can cause an increased rate of cell and tissue turnover**, resulting in damage and degradation.

A decreased level of these antioxidants can be a reason for a vulnerability of the connective tissue; an increased level can be a reaction of the body to counteract against an oxidative attack. Some results are:

Depending on the degree of the myopia of patients with retinal detachment an increased **lipid peroxidation** was found. Simulation of this process with animals resulted in a **decrease of the (protecting) glutathione peroxidase activity**[720]. Glutathione peroxidase contains selenium, whose impact on myopia has been mentioned before (section 3.24.16.1).

Myopes with a **lack of copper-zinc superoxide dismutase** are at a substantially higher **risk of vitreous degeneration**[152].

The activity of superoxide dismutase (**SOD**), which was increased (together with **NO**) by supplemental zinc (section 3.24.7), **prevented axial elongation** in myopia in animals[689]. Matching this result, the Chinese myopia medication "**Nacre**" is increasing the SOD activity in the eye[734].

There was a higher activity of glucose-6–phosphate dehydrogenase (**G6PD**) at myopes with progressive myopia than in myopes with stable myopia[721]

Note:
From this result it cannot be concluded that a higher level of G6PD causes myopia! Most likely, when myopia occurs, the defense system against oxidative damage is activated, herewith triggering the production of G6PD. So far there are no reports available about the correlation between inborn G6PD deficiency and myopia. It appears to be plausible that inborn G6PD deficiency might accompany myopia.

3.18.5 The Blood-Retinal Barrier

Definition of the blood-retinal barrier: "Specialized nonfenestrated tightly-joined endothelial cells that form a transport barrier for certain substances between the retinal capillaries and the retinal tissue."[722]

Rizzolo stated[723]: "The retinal pigment epithelium (RPE) is a monolayer that separates the outer surface of the neural retina from the choriocapillaris. Because the choriocapillaris is fenestrated, it is the RPE that forms the outer blood-retinal barrier and regulates the environment of the outer retina."

Experiments with animals showed an abnormally **increased permeability of the blood-retinal barrier in experimental myopia**. The question, however, is as Kitaya et al. stated[724], whether "impaired blood-retinal barrier function might be a secondary effect of myopia development rather than the cause of myopia."

Notes:

- *Additionally, it is possible that the impaired blood-retinal barrier as well as the myopia are caused not by each other, but are caused together by a special biochemical process.*
- *If an impaired blood-retinal barrier was responsible for myopia, selenium supplementation might be efficient against myopia via its retina-protecting effect (see section 3.24.16.1).*

G**lucose level** appears to be related to myopia as well (see section 3.24.1), and glucose has a significant impact on the blood-retinal barrier[725].

The blood-aqueous barrier appears to be intact in young high myopes with healthy posterior vitreous body and retina[726].

3.18.6 The Vitreous Body

The vitreous body consists mainly of a mixture of fluid and gel, where the gel acts, besides other functions, as a shock absorber against sudden stress and strain, which includes the forces caused by the saccades (see section 3.6). Gel is composed of collagen. When collagen structure changes, the relation between gel and fluid will be affected, in turn possibly destabilizing the retinal surface, which can cause retinal detachment.

Liquid is about 20% of the vitreous body at age 18 and progresses to more than 50% in old age[727].

Morita et al. stated[728]: "The results ... suggest that **liquefaction of the vitreous begins at a relatively young age in patients with high myopia** and progresses with age and axial elongation, thus resulting in a frequent occurrence of posterior vitreous detachment."

It was concluded that liquefaction is caused by the functional disorder of the **blood-retinal barrier in myopia**[61] (see section 3.18.5 about the blood-retinal barrier).

Some recommendations for maintaining the health of the vitreous body were given:

Avoid and/or protect against bright sunlight or sunlamps

Avoid excessive supplementation of vitamin C

Avoid excessive, unbalancing supplementation of zinc or copper

Avoid excessive intake of foods rich in phosphorous

3.18.7 Nitric Oxide (NO)

Nitric oxide has multiple effects on the eye[729].

On one hand **NO reduces myopia**:

There are indications that NO can serve to **relax ciliary muscles**[730, 731] and therefore Tokoro stated[732] that "... chemicals related to NO may be useful drugs to treat myopia." In other words, Schmidt stated[733]: "The endothelian dysfunction and reduced NI-generation are accompanied by increased tonus of the smooth muscles..." The ciliary muscle, which is responsible for accommodation, consists of smooth muscle fibers.

Zinc was found to **prevent experimental myopia**, accompanied by an **increase of NO and NO synthase** (NOS) and superoxide dismutase (SOD)[689]. The same was claimed for the Chinese medicine "**Nacre**"[734] (see section 3.25).

Chiou stated[729]: "It is possible that high **myopia can be prevented/treated with inhibitors of iNOS activity** and/or iNOS induction."

BJ Carr reported[735], "… that **myopia-inhibition by atropine is dependent on induction of nitric oxide** (NO), and that **exogenous NO is sufficient to inhibit experimentally-induced form-deprivation myopia (FDM) on its own**."

On the other hand **NO increases myopia**:

Experimental myopia was induced by the use of translucent goggles (form deprivation) or negative lenses. Injection with a Nitrous Oxide blocking agent prevented myopia[736, 737, 738].

The retinal degenerative lesion, which is found in high myopia, can be attributed to an overproduction of NO[729].

Note:
A damage of the retina, caused by the degradation of NO which produces toxic peroxinitrate, can be avoided by extracellular zinc, magnesium, and most likely by the vitamins B6 and B12.[739]

Additional effects are:

Chiou stated[729]: "The **retinal degenerative lesion is caused by iNOS** induction and overproduction of NO which leads to apoptosis of retina."

Experimental myopia caused a reduction in iNOS, which is the most powerful one of the NO generators[740].

NO has a significant effect on the **intraocular pressure IOP**, as well an increase as well as a decrease was reported[741, 742, 743]. For the impact of the IOP on myopia see section 3.7.2.

NO can **reduce retinal dopamine**[744, 745]. For the impact of dopamine on myopia see section 3.3.1. For the biochemical process of **light adaptation** there is an interaction of **dopamine and NO**[746].

Tamm et al. stated[747]: "The presence of intrinsic NOS-positive nerve cells concentrated in the inner parts of the ciliary muscle might indicate a physiological **role of nitric oxide for disaccommodation or fluctuations during accommodation**." For the impact of accommodation on myopia see section 3.2.

Ando et al. stated[748]: " These data indicate that NO is an important stimulator of **choroidal neovascularization** and that reduction of NO by pharmacological or genetic means is a good treatment strategy."

Zhu found[749]: "**Form-deprivation reduced the NO concentration**, the immunoreactivity of iNOS, and the expression of iNOS mRNA. The gradual restoration of normal vision was found after uncovering the eyes. But the **expression of iNOS mRNA was significantly higher than that of the controls at the first week after the unocclusion**."

Merida S reported[717]: "No significant difference appeared in the total nitrite/nitrate [nitrite NO_2, nitrate NO_3] levels between the C [control] and LM [low myopia] groups, but **a large significant difference was found in the total nitrite/nitrate levels of the HM [high myopia] group**."

An **explanation**:

Chiou stated[729]: "**Both underproduction and overproduction of NO could lead to various eye diseases**. ... Providing NOS substrates or NO donors to lower the intraocular pressure, increase ocular blood flow, relax ciliary muscle etc. On the other hand, immunological NOS (iNOS) is inducible only in pathological conditions by endotoxins, inflammation and certain cytokines...retinal degenerative lesion is caused by the iNOS induction and overproduction of NO..."

A simplified **summary**:

It appears that NO is good, but the excessive amounts of NO produced by iNOS are bad.

A review about the role NO plays for avoiding oxidative stress of the eye was compiled by Bosch-Morell et al.[750]

3.18.8 Cross-Linking of the Collagen of the Sklera by UV-Radiation and Roboflavin

It is well known that people with a reduced mechanical strength of the connective tissue are at a substantially increased risk for progressive myopia.

The **solubility of collagen** was increased and the proportion of insoluble collagen was reduced in the skin of both vitamin B2 as well as vitamin B6 deficient rats and the **mechanical stability of scleras** was improved by treatment with vitamin B2 (and UV irradiation), introducing additional cross-links.

Wollensak reported[865]: "**Collagen crosslinking induced by riboflavin-UVA [i.e. vitamin B2 and ultraviolet A irradiation], glyceraldehyde, and glutaraldehyde led to a significant increase in biomechanical strength in human and porcine sclera.** Using these methods, collagen crosslinking might become a treatment possibility for progressive myopia."

Ding Han et al. reported[751]: "The posterior sclera collagen crosslinking induced by riboflavin-UVA can slow down the progress of myopia and increase the sclera biomechanical strength in the guinea pig model of form-deprived myopia." For the UVA light they used a diode, which was emitting light of 370 nm.

As a consequence, the combination of **vitamin B2 (riboflavin) and ultraviolet A light was suggested for the treatment of progressive myopia, because this treatment improved the cross-linking of scleral collagen very significantly in experiments with animals**[867, 868]. It was said, however, **that further testing is necessary before its clinical application.**

Maybe the positive effect of outdoor activities on myopia can be explained at least partially by the UV light to which the eye will be exposed outdoors.

Notes:

The increase of indoor activities and the resulting decrease of exposure to ultraviolet irradiation may play, together with a changed diet (see section 4.1.2), a substantial role in the increase in myo-pia.

Maybe the positive effect of outdoor activities on myopia can be explained at least partially by the UV light to which the eye will be exposed outdoors.

Following this explanation sunglass should be used only in rather bright sunlight.

3.18.9 More Biochemical and Biomechanical Effects

Various biochemical and biomechanical effects, which were found in connection with experimental myopia (i.e. with animals), have been described in section 3.3.2. Some more of these effects, which were found at myopic people, are:

Increased **excretion of acid mucopolysaccharides** was found in the urine of patients with advanced myopia[752, 689]. Mucopolysaccharides are basic components of collagen and the connective tissue, which was found to be defective in the sclera of highly myopic patients. This indicates disturbances in their immune system.

People with a **reduced content of collagen** and a delayed decrease of soluble fractions of collagen with age in the posterior scleral regions of the eye were found to be at risk for myopia related problems[753]

Matching these results is the experience that myopes have a **decreased corneal thickness**, as well as **decreased endothelial density**[754].

Myopic eyes have a tendency to show a reduced content of collagen in the posterior scleral region and **diminished tensile strength of the fibers**[753].

Rada found[360]: "This overall thinning observed in highly myopic human eyes is associated with **thinning of collagen fiber bundles as well as with a reduction in the size of the individual collagen fibrils**...either due to abnormal fibril formation or due to the presence of accentuated breakdown or catabolism of the sclera." As these results were found in eyes after the death of donors, however, "... the **changes in the collagen fibrils may have occurred long after the myopia itself developed, and thus be a consequence, rather than a cause, of the myopia**."

Fibroblasts (which are constituents of collagen, and which are the only cell type in the sclera) **decrease** with increasing myopia, but increase during recovery from myopia[139].

Myopes have a high probability of **posterior vitreous detachment** (PVD), i.e. a liquefaction of the hyaluronic acid matrix of the vitreous and a collapse of the interfused network of collagenous fibrils, and finally detachment of the vitreous from the retina. This indicates that myopia is very often accompanied or caused by structural deficits of the connective tissue, which are caused by biochemical effects.

Some deviations from the normal **status of the hormones** testosterone, 17-ketosteroid, 17-beta-estradiol and cortisol were found[755], however no straightforward conclusions could be drawn.

Note:
*Estrogen increases **endothelial nitric oxide**[756] (see section 3.18.5 about the impact of NO on myopia), and extended **estrogen treatment** increases the activity of lysyl oxidase, an enzyme*

which is essential for the cross linking of collagen the structure of the collagen of the sclera is degraded in myopia)[757].

For people with extreme myopia the concentration of the amino acid **glutamate** was 10-fold increased[890].

Note:
Glutamate is important for the NO metabolism (see section 3.18.5 about the impact of NO on myopia).

3.19 Mental Issues

3.19.1 Stress and Cortisol

Several authors have discussed **stress as a significant reason for myopia**[7, 758] (see also section 3.2.1.12 about accommodation and the nervous system) Stress cannot induce myopia directly, but it can change parameters that influence the functionality of the eye. Here are some of the observations and statements about myopia in connection with stress:

The **opening of the pupil** is increased[252] (called mydriasis): this **reduces the depth of focus** and **increases aberrations** (see section 3.3.9 about aberrations).

Workers closely checking merchandise for faults (requiring **high and sustained concentration**) became myopic, while colleagues doing other near work were unaffected[93].

It was said that under stress, there is a reflex to adjust the eye to distant vision, i.e. relax the ciliary muscle and set the axes of the eye correspondingly parallel. Consequently, there is a **conflict between stress and near work**[174], where the ciliary muscle has to be activated, and the optical axes have to be adjusted to vergence. Result can be a degraded image, which may lead to myopia.

Another source, however, states that the stress-triggered sympathetic nervous system **causes the ciliary muscle to contract**, i.e. to adjust for near vision[759]. According to this model, there can be a negative impact on myopia, too: A permanent stress induced near accommodation results in a reduced image quality for distant vision and additionally can have an effect equivalent to excessive near work. Both effects can be responsible for the onset or progression of myopia.

Stress was shown to elevate the **body temperature**[575], and herewith damage connective tissue (see section 3.16 on the impact of the temperature on myopia).

There are conflicting results about the level of **cortisol** in myopes: Results of an increased cortisol level[760, 761] and results of insignificant differences were found[762]. A solution for this contradic-

tion was offered by stating that in general the cortisol level is increasing under **transient** stress. After **long-term exposure to stress**, however, there will be a decrease of the cortisol output[763]. Cortisol has a high impact on connective tissue by mediating reactions of the immune system, e.g. by decreasing inflammations, and by creating structurally defective connective tissue[764].

Overall, the impact of stress on cortisol level creates a definite risk for becoming myopic.

It was stated that the Bates-method (section 3.2.2) had achieved its results at least partly be reducing stress, i.e. by creating more relaxed vision[230, 231].

Note:
It is unknown, whether the experiments where degraded vision led to myopia created substantial stress for the respective animals.

Stress can increase the **intraocular pressure** (IOP)[765], and there is a substantial impact of IOP on myopia (see section 3.7.2).

Stress can cause the **vitamin C** level to drop rapidly[766], and vitamin C is important for connective tissue integrity.

Stress has a high impact on **calcium** metabolism. The impact of calcium metabolism on myopia is discussed in section 3.24.3.

Stress can have an impact on **blood sugar level and insulin production**, which in turn can have an impact on myopia (see section 3.24.1).

Stress can increase the excretion of **chromium**[767]. The impact of chromium metabolism on myopia is discussed in section 3.24.8.

During the **summertime and school holidays**, there is less progression of myopia[149, 150, 152]. Several explanations are possible: Less stress, less near work, more physical activities, or more exposure to the sun (vitamin D?).

Psychosomatic, i.e. stress and anxiety induced feelings were reported to be able to influence myopia[768].

The analysis of ocular examinations after the **extraordinary stress of an earthquake** showed that 30% of people were diagnosed with pseudo myopia, and 8% with various forms of strabismus or phoria. These people had not complained about their vision before[769].

Note:
From this observation it can be concluded that frequent mental stress can easily lead to a permanent prescription of inappropriately strong glasses, ***resulting in a permanent progression of myopia****.*

It was reported that the first prescription of glasses was frequently the time of **serious personal stress**[235].

The **Bates method** (see section 3.2.2.1) emphasizes relaxation of the eye as well as exercises of accommodation.

The higher level of **stress in some Asian countries** like Taiwan, Singapore and Hong Kong (triggered by ambitious schooling) has been at least partly blamed for the substantially higher prevalence of myopia in these countries.[770]

Wolffsohn et al. stated[771]: "The data show that for EOMs [early onset myopes] the **level of cognitive activity operating during the near and far tasks determines the persistence of NITM** [near-work induced transient myopia]; persistence being maximal when active cognition at near is followed by passive cognition at far." The tasks were either passively watching or active arithmetic calculations.

Davies et al. stated[772]: "**Increasing the cognitive demand led to a significant reduction in the accommodative response. The lag was clinically greater for LOMs** [late onset myopes] compared to EMMs [emmetropes] at both distance and near. Mean heart period showed a significant reduction with increasing levels of workload. LOMs exhibit a relative elevation of the sympathetic system activity compared to EMMs."

The conflict that **mental activity triggers accommodation towards far,** and near work which requires accommodation for near was discussed already in section 3.2.1.12

Bowan summarized[252] the **stress caused by reading and the positive effect of plus lenses** on it: "It actually provokes an avoidance response much like the "fight or flight" response: the heart rate increases; the pupils dilate; respiration can increase; adrenaline is produced; the perspiration rate increases - just as if an emergency were occurring. Two studies demonstrated this (Harmon, Pierce) and also that reading lenses *decreased* these responses."

Less sleep, high pressure by extensive studying and less satisfaction with the own personal situation, which all of them contributes to stress result in an increased likelihood of myopia (see section 3.21). Moreover, it was reported that insufficient sleep up- or downregulated 711 genes[773].

CM Jung et al. reported[774] **"Bright light exposure significantly reduced plasma cortisol levels at both circadian phases studied …".**

Zhang et al. reported about effects of the Covid-19 pandemic[775]: There were significant **associations between anxiety and spectacle power** [odds ratios (OR) = 0.89; 95% CI [confidence interval]: 0.81–0.98], [and] **sleep time** (OR = 0.53; 95% CI: 0.35–0.79) … **The greater the degree of myopia, the higher the anxiety score**. However, myopia was not found to be associated with depression."

Notes:

Stress can substantially contribute to the rapid increase of myopia in populations like the Eskimos: For these populations the traditional lifestyle brought a lot of mental stability, now replaced by modern lifestyle and modern media.

Stress, too, can be the reason that relaxing exercises (see section 3.2.2.1) are not a general remedy for myopia: relaxation cannot be achieved by simple physical exercising; to be successful it needs a relaxed mind as well.

In general, near work will always be accompanied by a significant mental concentration, which by itself, (not talking about the accommodative stress), will always create some mental stress.

For information about the impact of the nervous system on accommodation (which can be stress related) see section 3.2.1.12.

3.19.2 Personality and Mentality

Compared with other variables personality and mentality are harder to cover in scientific research. Some statements that were made are:

In section 3.2.1 I already reported a correlation between a better education, which is generally connected with more reading, and myopia. For general statements like "myopes are more intelligent" this has to be considered.

Indeed, statistical surveys have shown that myopic children **perform better** in school, independent of the social status of the parents[689, 776, 688, 777, 778.]

Correspondingly, according to results from Singapore, educational levels, personal income, professional occupations, and better housing are associated with higher rates of myopia[137].

In section 3.16 it was already reported that the higher the scores in an **examination** were, the higher was the difference in body temperature between examination and no-examination, and that an elevated temperature can damage the connective tissue of the sclera. Possible explanation: Students, who take examinations more seriously, achieve better results, but consequently they are more at risk of myopia.

Besides the correlation with intellectual performance, there was an elevated rate of **introversion** for myopes found among students[779].

50 to 60 % of the Japanese are said to be myopic, but only 2 % of the people in South America are[126]. The same author hints at a substantial difference with respect to **spontaneity** between these two populations.

Note:

There are many other variables, like the pressure to excel at school.

It was claimed that visual problems are frequently caused by the desire of a person, to avoid the confrontation with a specific aspect of her/his life or personality – i.e. **the person doesn't want to see it**[126].

In section 3.2.2.1 it was mentioned, how the **Bates-method tries to influence also the mind of the myopic person**, and not just mechanically the eyes only.

Saw et al. stated: "An interesting observation is that **nonverbal IQ** may be a stronger risk factor for myopia compared with books read per week."[780]

A hypothetical explanation for the potential reasons for the correlation between intellectual performance and myopia was given by Miller[781]: "... A single genetically controlled mechanism affects both brain size and eye size."

Note:

The correlation between brain size and intelligence is highly questionable. Smaller brain of women used to be a justification for unequal rights

A potential link might be the **immune system**: Myopia, and asthma and other allergies, were substantially higher among extremely mathematically and/or verbally excellent students[688].

Moreover, there is a close interaction between **vision and learning** in general, i.e. a person's way to face the complex situation of learning has an impact on the person's vision[782] – and vice versa.

In section 0 is was described that outdoor activities had a positive impact on myopia. This could be explained, however, by the fact that children with a lot of outdoor activities have a more extroverted personality in general.

Note:
A reader[783] of the Manual proposed this convincing summary:

Personality (introverted, shy)
↓
Behaviour (reading and other near-oriented hobbies)
↓
Over-accommodation
↓
Myopia

3.20 Why are some People not becoming Myopic, Independent from the Circumstances?

In general, as described before, these two basic mechanisms were made responsible for the onset of myopia:

- Near work associated stress

- Degraded image quality

Potential explanations for the fact that some people do not become myopic in spite of heavy near work associated stress are:

- *Their connective tissue of the sclera is very elastic. In contrast to a rather un-elastic, i.e. more plastic elastic tissue their sclera is not returning completely to its original dimension after the stress is gone. It compares to a balloon, which still has some kind of memory effect after the air was released. Additionally, some people who are "immune" against myopia might have a muscular eye-system, which is able to realax well after muscular stress.*

- *They have a mindset, which enables them to get rid of any kind of stress, which includes muscular stress and tension very fast.*

- *They have a specific dopamine metabolism and concentration in the eye; higher dopamine levels were found to work against the onset and progression of myopia, see section 3.3.3.*

Notes:

However, why are some people not becoming myopic in case simply a somehow degraded image quality is responsible for the onset oy myopia only? It is very unlikely that the optical properties of the eyes of the people have changed so dramatically within the last decades that it ccould explain the dramatical increase in myopia during recent times. The same is valid for the biochemical metabolism of the people.

Still, it is possible these individual properties have existed since a very long time already, and ***only the modern environment enabled them to show their consequences****. In other words, as it will be summarized in more detail in section 3.30.9, the reason that some people ar not becoming myopic can be seen just in a genetic architecture which makes them immune against the consequences of modern environment, especially against the load caused by very extensive nearwork. This, however, is different from just saying "their myopia is simply inherited".*

The potential and sometimes expressed conclusion that "myopia is just genetic, nothing can be done against it" ignores the fact that there are ways to eliminate or at least reduce the harmful features and herewith the negative results and consequences of the modern environment too.

3.21 A Study: Factors Associated with Myopia in School Children

You et al. summarized the results of a study with Beijing school children[784]:

"In our population-based study on a study population of more than 15,000 children [age 7 – 18 years] in Greater Beijing, the prevalence of myopia (≤ - 1.00 diopters in the worse eye) and myopic refractive error were significantly associated with

- higher age,

-female gender,

- key school type,

- higher family income,

- parental myopia,

- dim reading illumination,

- longer daily studying duration, [normally accompanied by long time near work]

- shorterduration of watching television (or computer),

- higher self-reportedprotein intake,

- feeling well about life and status,

- feeling tired,

- less physical activity [especially outdoor activities]

- short time of sleeping"

Boxes indicate that these issues were more explicitly mentioned in the discussion section of this paper due to their importance.

Obviously, several of these issues are interconnected, e.g. longer daily studying duration frequently accompanies less physical activieties, short time of sleeping, feeling tired and feeling well about life.

Only the items female gender and parental myopia are out of control of the specific individuals.

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3.22 Myopic Changes in Pregnancy

There is a tendency that during pregnancy a shift towards myopia or an increase of myopia takes place. This shift, however, is generally reversed after giving birth[785] or after lactation[786].

Note:
Consequently, fitting of new glasses during pregnancy should be handled with extra care to avoid an overcorrection at the time after the pregnancy.

3.23 COVID-19 and Myopia

Wang J et al. reported[787] about children in China: "A substantial myopic shift (approximately -0.3 diopters [D]) was found in the 2020 school-based photoscreenings compared with previous years (2015-2019) for younger children aged 6 (-0.32 D), 7 (-0.28 D), and 8 (-0.29 D) years. The prevalence of myopia in the 2020 photoscreenings was higher than the highest prevalence of myopia within 2015-2019 for children aged 6 (21.5% vs 5.7%), 7 (26.2% vs 16.2%), and 8 (37.2% vs 27.7%) years. The differences in spherical equivalent refraction and the prevalence of myopia between 2020 and previous years were minimal in children aged 9 to 13 years."

Erdinest et al. reported[788]: "The results showed that average increase in spherical equivalent refraction and axial length, … during the year of lockdowns was -0.73 ± 0.46D/0.46 ± 0.31 mm respectively, while the average increase in the year prior was -0.33 ± 0.27D/0.24 ± 0.21 mm."

Note:
Potential explanations:
- *Reduced Time spent outdoors*
- *More prolonged accommodation when staying at home reading or using smartphones.*

3.24 Impact of Nutritional Components

This section contains published information about two issues:

nutritionally affected biochemical parameters where myopes show a difference

experiences where nutrition was found to have an impact on myopia.

The results summarized in this section are based mainly on statistics. To be fair it should be noted that interpretation of the statistics can be very difficult: does a parameter, found to occur together with myopia really have an impact on the mechanism of myopia? It might occur due to an unrelated **association** only. (Remember? It can be said, e.g. that most of the children who run across the street and get hit by an automobile were wearing tennis shoes, so therefore, tennis shoes must have caused the acci-

dents. Obviously, the tennis shoes were only a common association, not a related factor.) As, however, people whose eyesight is threatened by myopia cannot wait for final scientific results the advice can only be to follow any recommendation, as long as following this recommendation does not imply a new risk.

Generally, nutrition can have a positive impact on myopia either

- by improving the stability of the connective tissue, especially of the sclera, and/or by
- suppressing an exaggerated feedback which is triggered by image quality effects as outlined in section 3.3.

Yang et al. summarized[789] "**Recent research suggests that collagens in the sclera play an important role in the development of myopia**."

Note:
There is no doubt that nutrition has an impact on the health of the individual collagen.

3.24.1 Carbohydrates, Blood Sugar Level, Insulin Metabolism

Some research papers showed an interaction between myopia and glucose metabolism:

Hyperglycemia, when the blood sugar rises, as in diabetes or after meals, causes hydropic **swelling of the crystalline lens, and myopia**. The reason of this thickening of the lens is a decrease in the tension of the zonular fibers. Vice versa there can be farsightedness as the blood sugar falls[790, 44]. The refractive error in cases of diabetes can change 1 or 2 D within a few hours[791].

For diabetic patients, refractive changes can go up to – 4.00 D, and changes can take several weeks. The degree of myopia after medication for diabetes was started is not somehow proportional to the residual hyperglycemia, but there is a transient hyperopic change when control of the hyperglycemia is becoming effective[792].

Hypoglycemia causes frequently **reduced contrast sensitivity**[793], which can have an impact on myopia as well (see section 3.3).

Glucose metabolism has an impact on the **saccadic movements** of the eye, which are essential for focusing[483] (see section 3.6).

Overall, **diabetics** appear to have a higher rate of myopia[794].

Accommodation is reduced in diabetic schoolchildren[795].

Malondialdehyde, a breakdown product of **lipid peroxidation**, was found in increased levels in diabetes and in people with high myopia[711].

Dielemans et al. stated[511]: "Newly diagnosed **diabetes** mellitus and high levels of blood glucose are associated with **elevated IOP** and high tension glaucoma."

Du et al. stated[796]: "Diabetes-like glucose concentration **increases superoxide production in retinal cells**, and the superoxide contributes to impaired viability and increased cell death under those circumstances."

Note:
Oxidative processes (see section 3.18.3) as well as retinal metabolism (see section 3.3) have been credited with causing myopia.

Lane stated[258]: "Young myopes statistically consume **more than triple the ratio of refined carbohydrates** to total carbohydrates, as compared to hyperopes, and this difference is most highly significant..." Moreover, the consumption of sucrose per head has risen e.g. in England from 6.6 kg in 1815 to 54.5 kg in 1979[797].

Note:
Maybe the effect lies not only in the high consumption of refined carbohydrates, but also to a great extent in the overall sub-optimal nutrition, e.g. a lack of folic acid and numerous other nutrients.

A change in nutrition toward a focus on food **rich in refined carbohydrates and sugar** was blamed for the dramatic increase in myopia: diets high in refined carbohydrates are **increasing blood sugar (hyperglycemia), insulin levels (hyperinsulinemia), and insulin resistance**, which in turn causes the growth of the eyeball[798, 799].

The explanations, which were given by Cordain et al.[798]:

- Elevation of insulin increases the levels of the insulin growth factor-1 (IGF-1), "a potent **stimulator of growth in all tissues**".

- "Reduced levels of the insulin like growth factor binding protein-1 (IGFBP-1) may reduce the effectiveness of the body's natural retinoids in activating genes that would normally **limit scleral cell proliferation**" (for the role of retinoic acid on myopia see section 3.3.1).

For example it is explained[800] that in pacific islands where people kept to the original diet of fish, yam and coconut no increase in myopia was observed, in spite of long schooling hours of the children. In contrast, a myopia rate of over 18% was reported for Hong Kong fishermen, who had never attended school[801]. The rate was even higher for those with schooling.

As **another evidence for this insulin-argument** it is noted by Cordain et al.[798] that "population studies have demonstrated that **people of Asian and Chinese descent tend to be more insulin resistant** (which, however, often increases to some degree the production of insulin) than people of European descent" – and the prevalence of myopia is especially high in Asia.

Glucose level has an impact on the functioning of the **blood-retinal barrier**, which is related to myopia (see section 3.18.5).

In experiments with mice **hyperglycemia combined with a lack of insulin** leaded to a significantly **increased number of mast cells in the sclera**[802].

Note:
An increased number of mast cells should result in an enhanced activity of the immune system, which can reduce the stability of the sclera. For information about myopia and the immune system see section 3.18.1.

Flickering light can protect against artificial myopia (see section 3.14.5), most likely by retinal vessel dilation. High blood glucose significantly reduces this flicker induced retinal vessel dilation[651].

Wu reported[803]: "**Incidence of moderate-high myopia** was also related to baseline age, nuclear opacities, glaucoma, male gender and **diabetes history."**

Feldkaemper et al. found that **insulin can have rather complex effects**[804]: "Given that insulin is used in the therapy of human metabolic disorders and proposed as an agent to treat corneal epithelial disease, its **powerful myopigenic effect**, which is mostly due to its effects on the optics of the anterior segment of the eye, merits further investigation."

Penha AM et al. reported[805]: "**Insulin injections** induced significant amounts or relative myopia in plus lens treated eyes and further enhanced myopia development during minus lens treatment."

Note:
Can already a diet, which is excessively rich in carbohydrates and which therefore, causes the insulin level to increase, increase the probability of the onset or progression of myopia?

Sheng et al. reported[806]: "In chick eyes, exogenous insulin prevents the choroidal thickening caused by wearing positive lenses and increases ocular elongation and scleral glycosaminoglycan (GAG) synthesis, an indicator of eye growth."

C Berticat et al. reported[807]: "The consumption of **refined carbohydrates significantly increased the probability of myopia for girls** (odds ratio [OR] = 1.07; 95% confidence interval [CI], 1.02–1.13) **but decreased it for boys** (OR = 0.94; 95% CI, 0.89–0.98)."

A number of **nutritional components are important** for the avoiding of **hyperglycemia. They were found to be related with myopia as well**: Manganese, Chromium, vitamin D and flavonoids (see section 3.24).

Moreover, hyperglycemia influences **biochemical issues, which were found to be related with myopia as well**: NO level, cytokine production, oxidative stress, and microcirculation.

This might support the thesis that hyperglycemia can play a role in the development of myopia.

Moreover, it was found that a disturbed blood sugar metabolism has an impact on the pulsatile ocular blood flow[808]. The blood flow appears to be connected with myopia (see section 3.17).

The **excessive increase in the consumption of soft drinks** can be expected to contribute significantly to hyperglycemia.

Notes:

- *Hyperglycemia (i.e. elevated blood sugar level) can be caused not only by nutrition (and inheritance), but also by **stress** and a **lacks of exercise**, etc. It is not restricted to people with type I diabetes (who are permanently depending on insulin), and older people with type II diabetes, but can occur temporarily independent of age, i.e. also in children, where the development and progression of myopia is most critical.*
- *Additionally, it was emphasized that it is very important to keep a diet that **avoids steep increases in blood sugar level**, i.e. to have a "low-glycaemic index-low-fat-high-protein" diet[809, 810]. - Very frequently these steep increases in blood sugar (hyperglycemia) later cause significantly lowered levels of blood sugar (hypoglycemia).*
- *The findings summarized above **do not mean** that many myopes are diabetic, or that diabetes is a frequent reason for myopia. They mean, however that **carbohydrate and insulin metabolism might very well have an impact on the development of myopia**.*
- *In contrast to the report about low rates of myopia in the pacific islands, a very substantial increase in myopia was observed for **Eskimos** (see section 3.1), and obviously, their dietary habits had been changed significantly.*
- *Maybe another issue of the changed nutrition is the changed **sodium/potassium ratio**.*

3.24.2 Is there a Connection between the Blood Sugar Level and Negative-Lens-Induced Myopia?

In section 3.24.1 it was described that an elevated blood sugar level can induce at least transient myopia. In section 3.3 it was described that inappropriate, additional negative lenses can cause permanent axial myopia.

Note:

*Personal suspicion: If an eye becomes temporarily myopic due to elevated blood sugar level, and if therefore negative lenses are prescribed, these lenses are inappropriate during phases with normal blood sugar level. They might **cause in this interval lens induced myopia**, resulting in an elongated eyeball, i.e. axial myopia.*

*If these cycles are sufficiently long, and are repeated, a **permanent progression** to myopia might follow.*

Additionally, the hyperglycemic swelling of the lens might change the **mechanical properties of the lens**, contributing to an accommodative **hysteresis** (see section 1.3.2.4) and the **aftereffect of accommodation** / the **accommodative lag** (see section 3.2).

3.24.3 Calcium, Vitamin D and Sunlight

Calcium, magnesium and vitamin D have strong interactions. Because of this, they are described together.

Tideman JW et al. stated[811]: "Lower 25(OH)D concentration in serum [an indication of a lack of vitamin D] was associated with longer AL [axial length] and a higher risk of myopia in these young children. This effect appeared independent of outdoor exposure and may suggest a more direct role for 25(OH)D in myopia pathogenesis" … " The relationships between 25(OH)D and AL or myopia were investigated using linear and logistic regression analysis. Average 25(OH)D concentration was 68.8 nmol/L (SD ± 27.5; range 4-211); aver-age AL 22.35 mm (SD ± 0.7; range 19.2-25.3); and prevalence of myopia 2.3 % (n = 62). After adjustment for covariates, 25(OH)D concentration (per 25 nmol/L) was inversely associated with AL (β -0.043; P < 0.01), and after additional adjusting for time spent outdoors (β -0.038; P < 0.01)." " This effect appeared independent of outdoor exposure and may suggest a more direct role for 25(OH)D in myopia pathogenesis."

An evaluation of statistical data for reported blindness due to malignant myopia in different states of the USA was done by compiling a chart with the rate of myopia per state, and distance to seacoast, annual hours of sunshine and the nutritional concentration of calcium, fluoride and selenium in each state. One result was an inverse correlation between malignant myopia and calcium content in the water as well as annual hours of sunshine96. Annual hours of sunshine can serve as a measure of vitamin D supply.

Note:
If there are more hours of sunshine it is more likely that more time is spent outdorrs, which was found to be positive (see section 3.8).

Starting in the 1930s Knapp, an American ophthalmologist was the first author to describe the impact of calcium and vitamin D according to his experiences in his ophthalmologic praxis[812]:

- "In the course of being fed vitamin D deficient, low calcium diets, the eyes of dogs and rats revealed clinical myopia."

- "Further research was conducted on humans, not patients with the usual slow progressive short sight, but painstakingly selected, highly progressive myopes from many thousands of patients. They were fed supplements of vitamin D and calcium. Over 50% of this rapidly progres-

sive group, whose myopia would reasonably be expected to progress rapidly, instead showed a decrease in their myopia, or remained stationary. One third of the series registered a reduction in myopia."

A publication of an ophthalmologist was getting high attention, because he claimed that by intake of animal protein progression of myopia in kids was reduced to only one third as before[813]. Later analysis revealed, however that what he accounted as the benefit of protein was the benefit of the calcium in the calcium caseinate he used [258].

Note:

Another possible explanation of this result is the fact that casein increases cNOS activity (see section 3.18.7 about the effect of NO on myopia.

Mutti summarized their research[814]: " myopes appear to have lower average blood levels of vitamin D than non-myopes."

Experimentally induced myopia in animals was severely increased if a calcium deficient diet was used. Surprisingly, this was not the case with a vitamin D deficient diet. Overall, however, Hodos concludes[665], "… variables that effect eye growth include nutritional deficiencies of calcium and vitamin D."

The highest concentration of calcium in the hair was measured in cases of increasing myopia, and calcium concentration was highest for myopes and lowest for emmetropes[258]. The literature about hair analysis states that elevated calcium levels are indicating not an oversupply with calcium but an accelerated calcium turnover in the body, caused e.g. by chronic stress, allergies or chronic infections[815].

Preterm children are frequently myopic. Children with very low birth weight received supplementation with calcium and phosphorus – in the unsupplemented group 61% became myopic, in the group with supplements only 11% became myopic[816].

During the summertime, the time of school holidays, the progression rate of myopia is significantly lower[150, 151, 152]. Part of the explanation may be a higher exposure to the sun, which means more supply of vitamin D, and more physical activities.

The positive effect of a medication containing "Nacre" (see section 3.25) was attributed to an increased content of calcium in various tissues of the eye[734].

The great increase in myopia found for Eskimos129 may be related to nutritional changes, e.g. a reduction in fat-soluble vitamins (i.e. vitamins A and D) by a factor of 10[817]. Other possible factors are the reduced time spent outdoors and the increased amount of near work connected with schooling.

There is a relation of myopia and caries of the teeth[689]. There is no doubt that caries is (among other reasons) related to calcium metabolism.

A connection between the "exposure to natural light [which has an impact on the vitamin D metabolism] during the early perinatal period" was drawn by Mandel[818]: "There were seasonal variations in moderate and severe myopia according to birth month, with prevalence highest for June/July births and lowest for December/January ... Mild myopia was not associated with season of birth or perinatal light exposure."

Prepas published the hypothesis[819]: "Close focusing in the absence of UV light [i.e. in the presence of artificial light] may provoke axial myopia."

Mutti DO et al. summarized their results[820]: "The hypothesis that time outdoors might create differences in vitamin D could not be evaluated fully because time outdoors was not significantly related to myopia in this small sample. However, adjusted for differences in the intake of dietary variables, myopes appear to have lower average blood levels of vitamin D than non-myopes."

Calcitriol, the active metabolite of vitamin D, appears to increase the level of dopamine[821]. Dopamine was found to play an important role in the onset of myopia, see section 3.3.3. Maybe the positive effect of sunlight and vitamin D is based on the positive effect on dopamine.

Choi JA reported[822]: "Low serum 25(OH)D concentration was associated with myopia prevalence in Korean adolescents [aged 13-18 years]. This relationship was particularly notable in adolescents with high myopia."

Similar results were reported from Western Australia as Yazar et al reported[823]: "… lower serum 25(OH)D3 concentration was associated with higher risk of having myopia (odds ratio [OR] for <50 vs. >50 nmol/L".

J McMillan reported[824] a significant improvement of astigmatism und keratoconus by vitamin D supplementation.

Jung BJ et al. reported[825]: "Linear regression analysis showed that as **25(OH) D level increased by 1 ng/mL, myopic refractive error significantly decreased by 0.01 D** ($P < 0.001$) after adjusting for potential confounders including sex, age, height, education level, economic status, physical activity, and sunlight exposure time."

Myopia and skin cancer are inversely correlated[826].

Willem J et al. reported[827]: "After adjustment for covariates, **25(OH)D concentration (per 25 nmol/L) was inversely associated with AL** [axial length], and **after additional adjusting for time spent outdoors.**

Risk of myopia (per 25 nmol/L) was OR 0.65 (95 % CI 0.46–0.92).

Lower 25(OH)D concentration in serum was associated with longer AL and a higher risk of myopia in these young children. This **effect appeared independent of outdoor exposure** and may suggest a more direct role for 25(OH)D in myopia pathogenesis."

Gao et al. reported for Chinese children[828]: "Logistic regression analysis showed that after controlling for gender, parental myopia, after-school class, and outdoor activities, **the prevalence of developing moderate and high myopia was 2.051 times (95% confidence interval: 1.272-3.724) higher in the serum 25(OH)D deficiency group than in the serum 25(OH)D sufficiency group**."

However, A review published in The Journal of the American Osteopathic Association found V**itamin D can't be metabolized without sufficient magnesium levels, meaning Vitamin D remains stored and inactive for as many as 50 percent of Americans**[838]**.**

3.24.4 Vitamin D and Dopamine

Cakir et al. stated[829] :**Vitamin D is known to increase levels of dopamine and its metabolites in the brain.**

Trinko et al. stated[830]: "… data demonstrate that dopamine circuits are modulated by D3 signaling, and may serve as direct or indirect targets for exogenous calcitriol."

Kesby et al. discussed in an extensive paper specific **implications of vitamin D status on the neurotransmitter dopamine**[831] .

The importance of dopamine on myopia is discussed in section 3.3.3 and section 3.14.2.

3.24.5 Selenium and Dopamine

Dopamine turnover was increased when rats were fed selenium deficient diet. The decrease in brain antioxidant protection caused by a nutritional deficit of selenium and a following decrease in glutathione peroxidase activity was made responsible for this effect.[832]

The key role which dopamine plays is described in section 3.3.3

3.24.6 Magnesium

Due to an inherited disorder in the magnesium metabolism **hypomagnesemia** (i.e. a lack of magnesium), combined with hypercalciuria (i.e. increases excretion of calcium in the urine) can occur. Often this defect is accompanied by myopia and nystagmus[833, 834, 835]**.**

It was concluded that the **Marfan syndrome** is related to metabolic magnesium deficiency[836] and to **excessive hyaluronic acid synthetase**[837]. People with Marfan syndrome are showing, among others, an extreme flexibility and mobility of their joints.

A review published in The Journal of the American Osteopathic Association found **Vitamin D can't be metabolized without sufficient magnesium levels, meaning Vitamin D remains stored and inactive for as many as 50 percent of Americans.**[838]

There is an old report by Algan[839] titeled "The treatment of progressive malignant myopia with magnesium chelates of flavones. Apropos of 400 cases" (no details are available).

Notes:
In general, magnesium is claimed to have a relaxing effect on smooth muscles, and therefore it might prevent or reduce accommodation cramps of the smooth ciliary muscle.

Furthermore magnesium has a positive effect on inflammation, and low magnesium intake is linked to chronic inflammation (about myopia and inflammation see section 3.18.2).

3.24.7 Copper and Zinc

Some results about the correlation between copper and zinc metabolism and myopia are:

Vinetskaia et al. stated[840]: "**Progressive myopia** was found **associated with reduced copper** content [in the tears] and **changed ratio zinc to iron**, this indicating certain metabolic disorders in the connective tissue system, in the scleral membrane first of all, and in the antioxidant defense system."

Qiang et al. stated[162]: "... there was a close relationship between juvenile myopia and ... **zinc/copper ratio** in hair ..."

For myopes above – 6.0 D a **statistically significantly decreased concentration of copper** in the serum was measured[841]

Note:
*A reduced content of copper in the serum can be observed only for an **already substantial lack of copper**[842].*

Avetisov et al. stated[843]: "Copper measurements in scleral tissue of 14 cadaveric emmetropic eyes and in 10 eyes with myopia of various degrees have shown a **significant reduction of copper** levels in the equatorial and posterior segments of myopic sclera and abnormal distribution of copper in the tissue, this indicating disordered metabolism of this trace element."

Patients with progressive myopia received **injections with a copper-pyridoxine** (pyridoxine is vitamin B6) compound near to the sclera to stimulate the formation of collagen and improve the cross-linking of connective tissue fibers. After 3 year the refraction was stable for 64% of the patients[844].

Patients with **low levels of diet-responsive copper-zinc superoxide dismutase** (CuZnSOD, an antioxidant enzyme) had a very substantially increased risk to develop structural defects in the vitreous body (*vitreous floaters*, which are common for myopes) than patients with a high level of CuZnSOD[152].

Eye drops containing zinc were inhibiting experimentally induced myopia in animals. It was concluded that this positive effect is due to a measured increased activity of superoxide dismutase (**SOD**), which prevents excessive processes of oxidation, and of nitric oxide (**NO**) and nitric oxide synthase (**NOS**)[845].

An Indian mixture containing "zinc, ascorbic acid and micronutrients" was taken in capsules, and was reported to improve the myopia in certain cases[846].

The Chinese myopia medication "**Nacre**" (see section 3.25) is containing zinc, copper and numerous trace elements, which results in **increased SOD, NOS and NO activity**[734].

Note:
Due to the numerous ingredients the principles of its efficiency are hard to judge.

A **Zinc compound** (the Indian medicine "Yashad Bhasma") was evaluated. A two months use produced improvements in myopia. The results were, however, statistically not significant[847].

Fedor M et al. reported[848]: "**The average serum concentration of zinc in myopic patients was significantly lower (0.865 ± 0.221 mg L-1) in comparison to the control group** (1.054 ± 0.174 mg L-1). **There was significantly higher Cu/Zn ratio in myopic patients** (1.196 ± 0.452) in comparison to that in the control group (0.992 ± 0.203)."

Zinc has a substantial impact on the dopamine metabolism[966]. About myopia and dopamine see section 3.25.4

Fedor M et al. reported[876]: "The **average serum concentration of zinc in myopic patients was significantly lower** (0.865 ± 0.221 mg L^{-1}) in comparison to the control group (1.054 ± 0.174 mg L^{-1}). There was significantly higher Cu/Zn ratio in myopic patients (1.196 ± 0.452) in comparison to that in the control group (0.992 ± 0.203). … **Low serum concentration of zinc and selenium in myopic children may imply an association between insufficiency of these antioxidant microelements and the development of the myopia and could be the indication for zinc and selenium supplementation in the prevention of myopia. Significantly, higher Cu/Zn ratio in the study group can suggest the relationship between myopia and oxidative stress.**"

3.24.8 Chromium

Some results about the correlation between chromium metabolism and myopia are:

Hair analysis was showing substantially **decreased chromium levels** for myopes, and especially for progressing myopia[258]. This was explained by a higher intake of refined carbohydrates, e.g. sugar. Sugar is said to deplete body stores of chromium. Matching with this is a result showing that myopes consumed only 39% as much fiber as hyperopes (i.e. farsighted people), which is interpreted as an increased consumption of refined food by myopes. Tissue chromium concentration was found to be negatively correlated with intraocular pressure (IOP) also (see section 3.7.2 on the impact of the IOP on myopia).

The explanation given by Lane[258] is that "... the importance of chromium in visual function is probably due to its role as the potentiator of **insulin** at the insulin-receptor sites in blood vessels supplying the ciliary muscle."

For the directly myopia related results of the impact of carbohydrates and insulin metabolism see section 3.24.1.

The ratio of **chromium to vanadium in erythrocytes is depressed** for myopes.[849]

The structure of the **retinal pigment epithelium** showed more damage for Chromium deficient rats[850].

Chromium deficiency showed abnormal reactions of the **immune system** in the retina of rats[851].

In myopic eyes of chicks a significant **decrease of chromium in the aqueous humor** was found[734].

3.24.9 Manganese

Persons with **high hair manganese concentrations** were found to show increasing hyper**opia or decreasing myopia[258].**

A deficiency in manganese results in a **loss of photoreceptor cells and capillary anomalies** in the retina[852].

3.24.10 Potassium

The concentration of potassium in the hair of myopes was found to be **very significantly lower** than in emmetropes or hypertropes[258] (highest concentration at hypertropes).

Wu S reported[853]: "we **found that the arrangements of ciliary muscles in LIM [lens induced myopia] guinea pigs were broken, dissolved or disorganized** …. **Monitoring of K [potassium] flux in ciliary muscles from LIM guinea pigs demonstrated myopia-triggered K influx.** … Overall, our results will facilitate the understanding of the mechanism associated with **inhibitory Na /K -ATPase [adenosine triphosphate] in lens induced myopia and which consequently lead to the disorder of microenvironment within ciliary muscles from LIM guinea pigs**, paving the way for a promising adjuvant approach in treating myopia in clinical practice."

3.24.11 Fluoride

A source in the Internet reported[854]: "Higher incidences of myopia as a result of excessive fluoride intake during childhood have been reported in India *(Raja Reddy, 2000)* as well as in Sosnivka, Ukraine *(Miroshnychenko, 2000).* It was found that myopia was much more prevalent in girls with dental fluorosis than boys, worsening at the ages of 10 to 11 and 12 to 13. *(Miroshnychenko, 2000)."*

Most likely, this negative effect on myopia is caused by defects of the connective tissue, induced by excessive doses of fluoride[855].

3.24.12 Salt

Li Q et al. reported[856]: "The results revealed that the high-salt diet aggravated ischaemia/reperfusion-induced thinning of the retina. … retinal ischaemia/reperfusion mainly results in neuronal degeneration, including thinning of the retina, retinal ganglion cell death. … a **high-salt diet aggravates ischaemia/reperfusion-induced retinal neuronal impairment by activating pro-apoptotic and pro-inflammatory signalling pathways and inhibiting vasodilation.**"

Inhibiting vasodilation has an impact on blood circulation, see section 3.17

3.24.13 Fat and Cholesterol

Lim LS et al. summarized their results[857]: "Higher saturated fat and cholesterol intake are associated with longer AL [axial Length] in otherwise healthy Singapore Chinese schoolchildren."

In section 3.3.3 the im pact of dopamine on myopia is discussed, and SO Ahmad[858] reported about experiments with rats "… findings support a role for n-3 PUFAs [n-3 polyunsaturated fatty acid] neurons and suggest that altered dopamine cell number, as well as function, behavioral effects observed in rats raised on n-3 PUFA-deficient diets.

Pan et al. reported[859]: "We demonstrated that daily gavage of ω-3 PUFAs (300 mg docosahexaenoic acid [DHA] plus 60 mg eicosapentaenoic acid [EPA]) significantly attenuated the development

of form deprivation myopia in guinea pigs and mice, as well as of lensinduced myopia in guinea pigs."

3.24.14 Vitamin A

In section 3.3.1 it was stated that retinoic acid is significantly involved in experimentally induced myopia (less all-trans-retinoic acid synthesis when myopia is built up). Whether vitamin A, the precursor of all-trans-retinoic acid, has any impact on this mechanism is unknown.

Besides this vitamin A (and zinc) are essential for night vision.

3.24.15 B-Vitamins

Some results about the interaction between B-vitamins and myopia are:

As reported in section 3.24.3 myopia is often accompanied by a disturbed calcium metabolism, measured by elevated calcium levels in the hair. Vitamin B6 (pyridoxine) is said to be able to **correct this disturbed calcium metabolism**[860].

Vitamin B6 and B3 (pantothenic acid) are said to be helpful in regulation of **intraocular pressure** (IOP)[162].

There was a correlation found between deficiencies of vitamin B1, B2 and B6, nystagmus, and **disturbed eye tracking**[861, 862]. Nystagmus is an uncontrolled, often rhythmical movement of the eyeball, and often accompanies myopia.

According to the title of a Japanese publication, juvenile myopia was treated with massive doses of vitamin B1[863].

Peroxide oxidation of lipids is intensified in progressive, complicated myopia. Also, antioxidant defense parameters in the tear fluid are decreased, resulting in structural and pathological changes in the retina. Success was achieved by applying **locally an antioxidant medication containing vitamin B6** (and emoxypin, a structurally analogue of vitamin B6) via a film, which was placed behind the lower eyelid every evening for 15 days[864, 713].

A lack of vitamin B6 is connected with an increase in the level of **homocysteine**, which can contribute to myopia. Homocysteine is discussed in section 3.24.17.

3.24.15.1 Riboflavin plus UVA [blue light]

Wollensak reported[865]: "Collagen crosslinking induced by **riboflavin-UVA [i.e. vitamin B2 and ultraviolet A irradiation]**, glyceraldehyde, and glutaraldehyde led to a **significant increase in biomechanical strength in human and porcine sclera**. Using these methods, collagen crosslinking might become a treatment possibility for progressive myopia."

M Sun et al. tested crosslinking induced by **riboflavin-UVA[866]: "** The biomechanical stability of sclera was increased. The scleral stress and Young modulus at **8% strain corresponded to 184% and 183%, respectively, of the control values at 12 months. No retinal damage was detected on histology.**"

As a consequence, the combination of vitamin B2 (riboflavin) and ultraviolet A light was suggested for the treatment of progressive myopia, because this treatment improved the crosslinking of scleral collagen very significantly in experiments with animals[867, 868]. It was said, however, that further testing is necessary before its clinical application.

Li X summarized experiments with Guinea pigs[869]: "**Guinea pigs** underwent 30 min of whole-body UVA irradiation after each gavage for 2weeks. For control groups, guinea pigs were administered vitamin C and underwent either whole-body UVA irradiation without 0.1% riboflavin solution or whole-body fluorescent lamp irradiation with or without0.1% riboflavin solution. Resultantly, myopia models were established with an increased axial length and myopic diopter. **Compared with myopic eyes in the control groups, the net increase in axial length, dioptre and strain assessment decreased significantly, and the net decrease in sclera thickness, ultimate load, and stress assessment decreased significantly in experimental groups.**"

Krasselt et al[870] concluded from experiments with rabbits: "… gentle cross-linking with riboflavin and UV-A or blue light might be a clinical approach in future."

Lai et al. confirmed[871] by experiments with Guinea pigs the ability of UVA light and riboflavin to inhibit lens induced myopia, but the inhibitory effect was reduced after stopping the treatment.

Note:
*The **increase of indoor activities** and the resulting decrease of exposure to ultraviolet irradiation may play, together with a changed diet, a substantial role in the increase in myopia.*

3.24.16 Some More Antioxidants

3.24.16.1 Selenium

Some results about the correlation between selenium metabolism and myopia are:

An evaluation of statistical data for **reported blindness due to malignant myopia in different states** of the USA was done by compiling a chart with the rate of myopia per state, and distance to seacoast, annual hours of sunshine and the nutritional concentration of calcium, fluoride and **selenium** in each state. As a result among others an inverse correlation between malignant myopia and selenium was found [96].

Rats fed a diet higher in selenium (200 μg/kg diet) had **fewer cellular degenerating capillaries in the retina and a higher central choroid than those fed a diet of 100** μg/kg. Both levels of selenium, however, resulted in a normal activity of erythrocyte glutathione peroxidase, which is considered to be a marker for selenium sufficiency[872].

Notes:

- *Retinal defects are closely related to higher grades of myopia (see sections 1.7 and 3.18.5).*
- *A reduced thickness of the choroid accompanies experimental myopia (see section 3.3.1).*
- *Statements of sufficient selenium in the diet may be wrong.*

The concentration of **selenium in the retina** of animals with excellent vision is up to 100 times as high as in the retina of animals with weak vision[873].

Selenium deficient diets reduced the **amacrine cells and the photoreceptor cells in the retina** of rats and mice[851, 874]. Amacrine cells were found to be important in deprivation experiments, where they were found to be involved in the dopamine signaling (see sections 3.3 and 3.24.4).

The expression of a selenoprotein in the retina of chickens was found to be increased after image degradation. This increase, however, took place after applying positive lenses (hyperopic defocus) as well as negative lenses (myopic defocus)[875].

Fedor M et al. reported[876]: " The average serum concentration of selenium in the study group was significantly lower (40.23 ± 12.07 μg $^{L-1}$) compared with that in the control group (46.00 ± 12.25 μg L^{-1}). … Low serum concentration of zinc and **selenium in myopic children may imply an association between insufficiency of these antioxidant microelements and the development of the myopia and could be the indication for zinc and selenium supplementation in the prevention of** myopia."

3.24.16.2 Flavonoids and Related Compounds, and Vitamin E

This family contains over 4000 different compounds. Some results of their effect are:

Orally to chicks administered **black-currant** significantly **inhibited the onset of myopia** which is normally caused by the application of negative lenses[877].

It was claimed that **cyaninoside chloride** is effective to treat progressive myopia by protecting collagen against enzymatic attack by collagenase, showing antioxidant activity[878, 879].

The **magnesium chelate of flavones** named Flacitran was found in long-term treatments to have a positive effect on complications of malignant myopia. This was explained by its ability to hinder the buildup of degrading enzymes collagenase, elastase, hyaluronidase, and of histamines[880]. Collagen, elastase and hyaluronic acid are components of the connective tissues, and the ending "ase" indicates the degrading property. Histamines are mediators of inflammations.

A medication containing **anthocyanosides** (e.g. bilberries) **plus vitamin E** had positive influence on progressive myopia and its consequences[881]. Similarly, diabetic retinopathies (which are caused by damages in capillary vessels) were successfully treated with anthocyanosides[882]. And there are numerous commercial claims that anthocyanosides from bilberries are helpful to treat myopia.

A medication containing **troxerutin plus vitamin E** had a positive influence on the progression of myopia[883]. The effect was claimed to be based on the antioxidant anti-hyaluronidase properties of vitamin E, and the anti-hyaluronidase and anti-histamine properties of troxerutin.

Bhutto et al. stated[884]: "...findings indicate that the **decrease in retinal capillaries** in vitamin E–deficient rats is secondary to retinal degeneration."

Vitamin E can inhibit the **hyperglycemia induced elevated production of superoxide** in the retina[796].

A **rutin compound** improved the **retinal microcirculation**[885]. For the relevance of microcirculation to myopia see section 3.17.

3.24.17 Folic Acid and Homocysteine

3.24.17.1 Observations

Some results about the interaction between homocysteine- and folic acid-metabolism and myopia are:

A strong correlation of **food-folate intake with a reversal of myopia**, and with some reduction of the intraocular pressure (**IOP**) was found. Supplementation with the pharmaceutical form appears to be less effective than intake of food-folate[512].

Note:
The positive effect could be explained not only by the positive effect of folate, but also with food ingredients which are can frequently be found in food which is rich in folate, e.g. flavonoid.

Numerous publications report high and very high myopia (among other symptoms) for people suffering from **homocystinuria**, an inherited defect that leads to abnormal high levels of the amino acid homocysteine in the serum[886, 887, 888, 889].

The concentration of the amino acid **methionine** was 10-fold increased for people with extreme myopia[890].

Mulvihill et al. stated[891]: "**Young persons with marked and progressive myopia … should be screened for homocystinuria**."

Marcucci et al. stated[892]: "...in animal models homocysteine is able to activate metalloproteinases." About metalloproteinases, agents that can degrade connective tissue, Jones et al. stated[352]: "Scleral matrix metalloproteinases, serine proteinase activity and hydrational capacity are increased in myopia induced by retinal image degradation." In other words, **an elevated level of homocysteine can have similar biochemical effects as retinal image degradation**.

3.24.17.2 An Explanation

A very short explanation of the biochemistry that links the referenced observations[893, 894, 895]:

Homocysteine is built from the other amino acid methionine by the metabolism as an intermediate product: Normally homocysteine is quickly recycled to methionine or finally transformed to cysteine. For these transformations especially folic acid, vitamin B6 and vitamin B12 are needed. A missing transformation can have genetic reasons, or a lack of appropriate quantities of folic acid, vitamin B6 and vitamin B12.

Elevated levels of homocysteine, which is a powerful oxidant, can be the source of various serious health problems, including degraded cross-linking of collagen.

A high intake of **proteins**, especially of meat, contains a high quantity of methionine and increases therefore the demand especially of folic acid and of vitamin B6.

3.24.18 Bilberry and Anthocyanins

IHN Omar et al.[896] investigated the effect of bilberry on the progression of high myopia (about –10 D) in children with an age of 9 years. Bilberry extract was given for 1 year, and then stopped for the 2. year.

	Bilberry group	Control group
Difference in refraction after 12 month	0.12 D	0.39 D
Difference in axial length after 12 months	0.26	1.03
Difference in refraction between month 12 and 24	0.1 D	0.3 D
Difference in axial length between month 12 and 24	0.2	0.3

Obviously, the positive effect remained still after the break of 12 months.

Kamiya reported[897] significantly increased amplitude of accommodation by taking fermeted bilberry extract.

Y Nomi et al. reported[898]: "In vitro study, AC [anthocyanin] had a **relaxing effect on ciliary muscle** which is important to treat both myopia and glaucoma. And AC stimulate the regeneration of rhodopsin in frog rod outer segment. Furthermore, **AC could inhibit the axial length and ocular length elongation** in a negative lens-induced chick myopia model. In addition, we summarized clinical studies of AC intake improved dark adaptation and transient myopic shift and the **improvement on retinal blood circulation** in normal tension glaucoma patients."

About blood circulation and myopia see section 3.17

Plants rich in anthocyanins are such as blueberry, cranberry, bilberry, black raspberry, red raspberry, and blackberry, blackcurrant, cherry, eggplant (aubergine) peel, black rice, ube, Okinawan sweet potato, concord grape, muscadine grape, red cabbage, and violet petals.

3.24.19 Lactoferrin

Ikeda et al. reported[899] results about oral administration of lactoferrin (an iron-binding protein present in saliva, tears, and mother's milk) on mice with lens induced myopia (LIM): "The eyes with a minus lens showed a refractive error shift and an axial length elongation in the control group, thus indicating the successful induction of myopia. **However, there were no significant differences in the aforementioned parameters in the LF group.** While LIM increased IL-6 expression and MMP-2 activity, it decreased collagen 1A1 content. However, orally administered LF reversed these effects. Thus, **oral administration of LF suppressed lens-induced myopia devel-**

opment by modifying the extracellular matrix remodeling through the IL-6-MMP-2 axis in mice."

Kuruyleva et al. reported[900]: " Concentration ratio of lactoferrin and lysozyme in TF ([Ltf]/[Lys]) was evaluated as the ratio of protein band intensities. … **[Ltf]/[Lys] ratio was greater in moderate myopia than in high myopia**: 0.88 [0.75; 1.01] and 0.6723 [0.60; 0.78], respectively. **Emmetropes demonstrated the highest [Ltf]/[Lys] ratio** - 1.59 [1.43; 1.98]."

Note:

Lactoferrin is a widely available supplement and is supposed to help the immune system, prevent inflammation and support iron absorption.

Lepanto et al. reported[901]: "Since the first anti-microbial function attributed to Lf [lactoferrin], several activities have been discovered, including the relevant **anti-inflammatory one, especially associated to the down-regulation of pro-inflammatory cytokines, as IL-6**. … Lf administration reduces local and/or systemic inflammation."

3.24.20 Crocetin

Crocetin is an agent derived from saffron.

Mori et al. reported[902]: "The c**hange in SER [spherical equivalent refractions] in the placebo group, -0.41 ± 0.05 D** (mean ± standard deviation), **was significantly more myopic compared to that in the crocetin group, -0.33 ± 0.05 D** (p = 0.049). **The AL elongation in the placebo group, 0.21 ± 0.02 mm, was significantly bigger than that in the crocetin group, 0.18 ± 0.02 mm** (p = 0.046). In conclusion, dietary crocetin may have a suppressive effect on myopia progression in children …"

3.24.21 Other Components of the Diet

Some results about the impact of a few other nutrients on myopia are:

Lane stated[860]: "Young myopes who are not increasing in myopia have a significantly lowered distribution of **flesh protein** intake compared to the distribution for young persons whose eyes are getting relatively more myopic..."

Note:

The more indirect reason might be that a diet more rich in meat would require higher amounts in other components of the diet (like vitamin B6 to keep homocysteine levels down, see section 3.24.17). Similar indirect nutritional effects appear to be very common.

It was claimed that **glutamate**, which is used extensively in the food industry is responsible for numerous health problems, including blurred vision and myopia[903]. In section 3.18.9 is referenced: "For people with extreme myopia the concentration of the amino acid **glutamate** was 10-fold increased."[890]

3.24.22 Overall Nutritional Status and Myopia

So far nutritional components were mentioned, whose specific lack was found to be correlated with myopia. On the other hand, myopia exists primarily in developed countries, where under-nutrition is no problem at all.

Some **statistics**:

Josephson stated[904]: "... noted that the percent of schoolchildren with **myopia rose and fell with the severity of the depression**, and linked that to nutrition: In 1925, it was reported that 25% of the schoolchildren attending a group of clinics in New York were afflicted with near-sightedness. With the advent of the depression, the figure rose steadily from over 40% in 1932 and to 72% in 1935. Reflecting re-employment and improved nutrition in 1936, the percentage incidence of near-sightedness dropped to about 51%. In 1937, the figure dropped to 42%."

Edwards et al. stated[905]: "Children who developed myopia had a generally lower intake of many of the food components than children who did not become myopic. The differences were **statistically significant for energy intake, protein, fat, vitamins B1, B2, and C, phosphorus, iron and cholesterol**. Despite these differences, children who became myopic were neither shorter nor lighter..."

Note:
When children become myopic the nutrition-based conclusion does not have to be that they are getting less of specific nutrients. More likely, their individual demand for specific nutrients is higher.

Some **explanations**:

The lack of specific nutritional components shows its effect on myopia only when it is **connected with extended near work**, i.e. in countries with a high rate of literacy. This high rate of literacy is often correlated with a lot of **indoor-time**, i.e. a potential lack of vitamin D (sunlight) and of physical activities.

In developed countries the content of the individual components of the nutrition has been **changed** by far more than in countries where under-nourishing is still a problem, but where the traditional food is still the same as long ago.

Moreover, the critical issue might be not the absolute content of a specific nutrient, but the **balance** between various nutrients (see section 3.24).

Spanheimer et al. stated[906]: "Malnutrition is associated with **defects in connective tissue** metabolism..."

3.25 Pharmaceuticals

Wang et al.[907] prepared an extensive review on pharmaceuticals with respect to myopia.

3.25.1 Atropine

Overall, attempts to treat myopia by pharmaceutical agents (not considering the nutrients discussed in section 3.24) haven't led to generally accepted, positive results. Some results are[949, 908]:

The main pharmaceutical agent tried for myopia, is **atropine**[909]. Atropine is used commonly as a cycloplegic agent **to relax the ciliary muscle** completely before determining the refraction, especially for children. It was reported in many papers that **atropine shows positive results** at least for several years[281, 910, 911, 912, 913, 914, 915, 916, 917, 918].

Grosvenor et al., however, stated[919] it "does not stop the progression of myopia, but **only delays it**", i.e. a positive impact during application was counterbalanced by an increased progression after stopping the application.

This argument of the delayed myopia was investigated by Tong et al., and they summarized their results[920]: "After stopping treatment, eyes treated with atropine demonstrated higher rates of myopia progression compared with eyes treated with placebo. However, **the absolute myopia progression after 3 years was significantly lower in the atropine group compared with placebo**" (-4.29 +/- 1.67 D versa 5.22 +/- 1.38 D).

A report of **weekly applications of a 1% atropine drop per eye told of a roughly 50% success rate to stop the progression of myopia for children**[921]. Similar positive results were obtained with the application of **0.05% atropine solution every evening**[922]. This is claimed to be the summary of a ten-year experience with hundreds of children. Additionally, Luu CD et al. found[923] that the are no side effects of common atropine doses: "Daily atropine usage [1% atropine sulphate] over 2 years for the treatment of myopia has **no significant effect on retinal function** as demonstrated by recordings of mfERG [multifocal electroretinogram]."

Another approach is to combine the application of atropine with the concept of undercorrection for near work. Shih YF found[281]: "**The 0.5% atropine with multi-focal lenses can slow down the progression rate of myopia. However, multi-focal lenses alone showed no difference in effect compared to control.**"

Daily nighttime Atropine application of only 0.025% resulted in a prevention of the onset of myopia for young children for a 1-year period[924].

During application, **attention has to be paid to avoid phototropic effects** caused by an excess of light hitting the retina (as the pupil is staying wide open)[139] and to provide binocular glasses for near work. There are other cycloplegic agents, which were examined (like tropicamide), with no convincing success, however[925].

Cooper J et al. summarized[926]: "**Atropine 0.02%** is the highest concentration that does not produce significant clinical symptoms from accommodation paresis or pupillary dilation. This would be an appropriate starting point in evaluating a low dosage of atropine to slow myopic progression."

A result from experiments with chicks only, published by Schwahn et al. [927], is: "Atropine suppressed myopia only at doses at which severe nonspecific side effects were observed in the retina."

Tests with experimental myopia at animals showed that **injections of atropine**, which can help to increase dopamine levels in the eye, were successful only at high doses, which were accompanied by serious side effects in the retina[927]. In this experiment Atropine increased the **release of dopamine** (for the impact of dopamine on myopia see section 3.3.3).

The effect of atropine on myopia cannot only be explained by its impact on the ciliary muscle (i.e. the blocking of accommodation) and the dopamine metabolism, but also by its reduction of the release of histamine[928], an agent of the **immune system**, which also helps to attack connective tissue. McBrien[929] confirmed that the reduction of experimental myopia is taking place via a nonaccommodative mechanism.

Atropine works not just by relaxing the ciliary muscle, but it modifies the sclera as well. Gallego et al. reported[930]: If the signals that induce growth remain during atropine treatment, morphological changes in sclera are produced: **the scleral fibrous layer thickened, and the sceral cartilaginous layer thinned.** These changes resulted in refractive error recovery, and the ocular growth was stopped. The data suggested the atropine was acting throughout the scleral fibrous layer."

From Experiments with chicks, it was concluded that the **effect of atropine is not based on the blockade of accommodation, but on effects on the neurotransmission in the retina[931]**.

The **maximum dose of atropine**, which did not result in clinical symptoms, was found to be 0.02%[932].

Chia A et al.[933, 934] compared the effect of 0.5%, 0,1% and 0.01% on the progression of myopia. **The result was that 0.01% is most effective and its effect was more lasting than the other concentrations**.

For children with **progressive myopia ≥ 1D/year atropine 0.05%** was used successfully[935]

Clark TY reported their results for the application of 0.01% atropine eyedrops[936]: "A retrospective case-control study was performed on 60 children (6-15 years) with initial myopic spherical equivalents from -0.25 to -8.00 diopters … **After 1.1±0.3 years follow-up, atropine subjects had significantly lower rates of myopic progression (-0.1±0.6 D/year) than controls (-0.6±0.4 D/year)** (P=0.001), including 24 of 32 (75%) with slow progression ≤-0.25 D/year versus only 5 of 28 (18%) controls. Three atropine and 4 control subjects had rapid progression ≥-1.00 D/year".

According to a summarizing report by Smith et al. [1031] treatment with for Atropine resulted in an average slowing of myopia progression by 77% (average of multiple independent trials).

Schwahn et al. reported[937]: **"Atropine increased the release of the neurotransmitter dopamine …"** and dopamine was reported to slow down progression oy myopia (see sction 3.25.4)

Note:
In case the positive effect of stropine is just based on the release of atropine, Grosvenor[919] is right when he says atropine is delaying the myopia only [as it may proceed when the additional dopamine is no longer available].

Results of atropine with the higher concentration of 1.0 % are[938]: After 4 years the final mean myopia progression per year in the experimental group was significantly decreased when compared to that in the control group: -0.29± 0.17 D vs -0.89±0.44 D.

Obviously the **effect of atropine is not based on its effect on accommodation**, as it is reducing the progression oy myopia on birds, where it is not affecting accommodation[445].

The question of **how permanent the effect of atropine is after discontinuation** was investigated by A Chia et al.[939]: "Pupil size and near visual acuity returned to pre-atropine levels in all groups, but accommodation at 36 months was less in the 0.5% eyes (13.24 ± 2.72 D) compared to the 0.1% (14.45 ± 2.61 D) and 0.01% eyes (14.04 ± 2.90 D, P < 0.001). The overall increase in SE [spherical equivalent] over the entire 36 months [24 months atropine, 12 month off] in the 0.5%, 0.1% and 0.01% groups was -1.15 ± 0.81 D, -1.04 ± 0.83 D and -0.72 ± 0.72 D, respectively (P < 0.001) ….. Conclusion: **There was a myopic rebound after atropine was stopped, and it was greater in eyes that had received 0.5% and 0.1% atropine. The 0.01% atropine effect, however, was more modulated and sustained.**"

Lin et al. reported[940]: "We found **atropine downregulated inflammation** in MFD [monocular form deprivation] eyes. The expression levels of c-Fos, nuclear factor κB (NFκB), interleukin (IL)-6, and tumor necrosis factor (TNF)-α were upregulated in myopic eyes and downregulated upon treatment with atropine."

Note:

The explanation that the efficacy of atropine is based on its anti-inflammatory effect would explain that there is a rebound effect: When atropine is discontinued inflammatory processes might start again.

Anders et al. concluded[941] that the **effect of atropine on myopia is independent from dopamine** metabolism.

Kaymak et al. reported[942]: "The atropine effect on **axial length growth averaged to 0.08 mm (28%) inhibition per year. Effects on refraction were not statistically significant. …** Conclusion: The observed atropine effects were **not very distinctive**: Statistical analysis confirmed that atropine reduced axial length growth, but to an extent of **minor clinical relevance**. It was also shown that **beneficial effects of 0.01% atropine may not be obvious in each single case, which should be communicated with parents and resident ophthalmologists."**

Yam et al. reported[943]: "**Low concentration atropine induced a choroidal thickening effect along a concentrationdependent response** throughout the treatment period. The **choroidal thickening was associated with a slower SE progression and AL elongation** among all the treatment groups."

3.25.1.1 Comparison of Various Concentration of Atropine

Results of a trial with 400 children ages 6-12 years to whom atropine drops were appied once nightly, published by Chia et al.[944]: The **mean myopia progression at 2 years was**

0,5 % **-0.30±0.60 D**
0.1 % **-0.38±0.60 D**
0.01 % **-0.49±0.63** D

In comparison, **myopia progression in ATOM1 was**

1 % **-0.28±0.92 D**
placebo **-1.20±0.69 D**

They concluded. "Atropine 0.01% has minimal side effects compared with atropine at 0.1% and 0.5%, and retains comparable efficacy in controlling myopia progression."

Myopic changes measured at the LAMP study[945] for different **low concentrations of atropine** were after one year:

0.05 % **- 0.27 +/- 0.61 D**
0.025 % **- 0.46 +/- 0.45 D**
0.01 % **- 0.59 +/- 0.61 D**
placebo **- 0.81 +/- 0.53 D**

"All concentrations were well tolerated without an adverse effect on vision-related quality of life."

Another comparison of different atropine concentrations[946]:

0.5 % atropine **4.3 % poor responders with > 1.5 D progression per year**
0.1 % **6.4 % poor responders**
0.01 % **9.3 % poor responders**
and
0.05 % **4 % increase > 0.75 D per year**
0.025 % **17 % increase > 0.75 D per year**
0.01 % **33 % increase > 0.75 D per year**

The mean width of the pupil at different illuminations and different concentrations of atropine is[445]:

	control	0.01%	0,1%	0,5%
Low light:	4,4 mm	5.5 mm	6.9 mm	7.8 mm
Bright light:	3.9 mm	5.1 mm	6.7 mm	7.5 mm

3.25.1.2 Atropine plus Ortokeratology

Zhou et al. reported[947]: "Following two years of treatment, the **average spherical equivalent refraction change was** 0.88 ± 0.31 D [0.01 % atropine plus orthokeratology] and 1.14 ± 0.63 D [0.01 % atropine] in the combination group and atropine group, respectively."

3.25.2 7-Methylxanthine

In a trial by Trier et al.[948] 68 myopic children took 7-methylxanthine tablets for two years, and as a result the progression of myopia was substantially slowed down.

They reported: "… in the second year of the intervention period, average axial growth among children with a high base-line axial growth rate treated for all 24 months with 7-mx, **was reduced to 0.22 mm per year from an initial 0.52 mm per year at base-line**."

After stopping the treatment, however, the progression increased again. The treatment was reported to be safe and without side effects.

3.25.3 Other Pharmazeutical Agents

Related antimuscarinic agents like **pirenzipine** are being evaluated[949]. Some first and positive results were reported[950, 951, 952]. Pirenzipine is said to be **more selective**, i.e. not having the side effects as severe as atropine on the iris (mydriasis), on the accommodation and the ciliary muscle[953, 954].

Wallien et al. summarized randomized controlled studies[1030]: "The **largest positive effects for slowing myopia progression were exhibited by anti-muscarinic medications**. At one year, children receiving pirenzepine gel (two studies), cyclopentolate eye drops (one study), or atropine eye drops (two studies) showed **significantly less myopic progression** compared with children receiving placebo."

Adrenergic agents (like timolol or metipranolol) are intended to decrease the intraocular pressure (IOP) as a potential reason for myopia. One author claimed to have success in treating myopia with the IOP-lowering **beta-blocker** Metipranolol[506], but other authors could not confirm this by using the other beta-blocker timolol[507]. Further research in this area is going on[955].

The **Chinese medicine "nacre"** was used for tests with experimental myopia of animals. Nacre eye drops are made of the shell of pearls and consist of numerous trace minerals and amino acids. It was claimed that experimental eye elongation was reduced compared to control groups, and SOD activity and NOS activity, as well as NO content were increased. Moreover, the content of various minerals (calcium, zinc, chromium) in eye tissues was changed by this medication [734].

Note:
Due to the numerous ingredients the principles of its efficiency are hard to judge.

For the treatment of choroidal neovascularization, which can accompany pathologic myopia (**CNV**, see section 1.7) there is a rather new therapy with the agent **verteporfin (trade name Visudyne)**. Activation of verteporfin by light (**photodynamic therapy**), in the presence of oxygen, creates short-lived reactive oxygen radicals, which results in local endothelium damage, resulting in occlusion of vessels.

Chiou stated[729]: "It is possible that high **myopia can be prevented/treated with inhibitors of iNOS activity** and/or iNOS induction." Currently, however, there appears to be no practical treatment with these agents yet.

Trier et al. steted[956]: "Methylxanthine, a metabolite of caffeine, **increases collagen concentration and the diameter of collagen fibrils in the posterior sclera**, and may be useful for treatment or prevention of conditions … such as **axial myopia** …"

For the future there are expectations of handling myopia more effectively by influencing the biochemistry of the retina, e.g. by increasing the dopamine level, than by influencing the strain on the ciliary muscle as was tried before[957, 958].

3.25.4 Dopamine – a Summary

See also section 3.3.3 and section 3.24.5.

3.25.4.1 What Impact has a low Level of Dopamine?

- For myopia development and dopamine see section 3.3.3 and section 3.24.5
- A spasm of the ciliary muscle caused by excessive accommodation was made responsible for the onset of myopia: see section 3.2.1.7. A lack of dopamine in the brain can cause muscle spasms in general[959].
- In section 3.19.2 a linkage between personality and myopia was discussed. Dopamine was found to have a strong impact on the brain and herewith the personality[960, 961] . Simply generalized, the message was "low dopamine results in myopia and introversion".
- In section 3.17 it was mentioned that dopamine can increase the retinal perfusion, and that myopia is accompanied by reduced choroids blood flow.

3.25.4.2 What Increases the Level of Dopamine?

The importance of a high level of dopamine for the inhibition of the onset and the progression of myopia was already described in section 3.3.3

- Light, especially blue light, see section 3.3.3
- Flickering light, see section 3.3.3
- Pharmaceuticals like Atropine[937], see section 3.25.1
- Vitamin D, see section 3.24.4
- Selenium, see section 3.24.5
- Curcumin[962, 963, 964]
- Other components of the diet: Omega 3[965], Zinc[966], Dairy foods such as milk, cheese and yogurt, Unprocessed meats such as beef, chicken and turkey, Omega-3 rich fish such as salmon and mackerel, Eggs, Fruit and vegetables, in particular bananas, Nuts such as almonds and walnuts, Dark chocolate[967]
- Experiments with dopamine eye drops on animals showed positive results for preventing form deprivation myopia and lens induces myopia[968, 969].

3.25.4.3 Is the Couple Dopamine / Melatonin a Key-Player?

Effects of dopamine on myopia were mentioned above in numerous sections, i.e. in 3.3.1, 3.3.3, 0, 3.14, 3.17, 3.18.7, 3.24 and 3.25.1.

Effects of melatonin on myopia were mentioned in sections 3.3.3, 3.14.4 and 3.16.

A search in PubMed with the words "dopamine melatonin" results in 862 hits (as of 2019-04-26), which indicates the close relationship with each other.

Some results with respect of the interworking between melatonin and dopamine are:

Myopes have significantly **higher serum melatonin concentrations** than non-myopes[671, 672].

Iuvone et al. reported about experiments with chicks[970]: "**Melatonin inhibited the effect of dopamine** at all dopamine concentrations, suppressing the maximal response to the neurotransmitter by approximately 70%. …"

Doyle et al. reported about experiments with the mous retina[971]: "melatonin. Our results also indicate that **circadian rhythms of retinal dopamine depend upon the rhythmic presence of melatonin, but that cyclic light can drive dopamine** rhythms in the absence of melatonin."

Ostrin summarizes numerous resultsby various authors[972]:

"In the inner retina, **melatonin modulates dopamine release**."

"Melatonin and dopamine are both under circadian control, and **have antagonistic effects in the retina, with melatonin release in darkness, and dopamine release in response to light. Melatonin inhibits dopamine release from amacrine cells**."

"A study in chicks showed that systemic administration of melatonin resulted in significant alterations in growth of several ocular tissues in both control animals and those undergoing experimental myopia. Specifically, **significant changes were observed in anterior and vitreous chamber depths and choroidal thickness in all animals receiving melatonin. The results suggest that melatonin is involved in the regulation of ocular growth diurnal rhythms**, although the exact mechanisms remain elusive."

"Results showed that guinea pigs raised in green light had significantly higher levels of pineal gland melatonin, whereas guinea pigs raised in blue light had decreased melatonin, presumably as a result of increased ipRGC-induced melatonin suppression. Additionally, guinea pigs raised in green light developed more myopic refractive errors than those raised in blue light."

G Yan et al. reported[973]: "**High energy-consumption in retinal pigmented epithelium (RPE) cells** poses **oxidative stress (OS)** and contributes to mitochondrial dysfunction (MD) for retinal degeneration-associated diseases. In the present … we confirmed **the protective role of Melatonin against H O -induced mitochondrial dysfunction in RPE cells**."

Hussain et al. reported[650]: "Myopes were found to have significantly lower concentration of serum dopamine … myopes showed significantly lower serum melatonin concentration … Myopes exhibited lower concentration of tear dopamine ... myopes showed significantly lower tear melatonin concentration. … **The observed changes in the decreased concentration of Dopamine and Melatonin among young adult myopes and its association with refraction indicates the role of altered circadian rhythm in the human myopia mechanism**."

Note:
Conclusion: Excessive accommodation > high-energy consumption > melatonin-level is increased > dopamine level is decreased > eye is lengthened, onset or progression of myopia.
Abbreviated: Excessive accommodatin > myopia
The related impact of temperature on the onset of myopia is discussed in section 3.16
This still leaves the question, why this circle of events does not lead to myopia for many people.

With respect to this effects of melatonin and its interworking with dopamine it has to emphasized that the positive role of dopamine is established in the literature, see section 3.3.3

3.26 Other Means to Slow Down or Stop Progression of Myopia

3.26.1 Contact Lenses

Numerous experiences and experiments of ophthalmologists have shown that wearing **RGP (rigid gas permeable) contact lenses** instead of glasses can **slow down the progression of myopia** substantially[974, 975, 976, 987,988]. New studies, however, **denied this**[977, 978].

This positive effect has not been claimed for **soft contact lenses**[979] **and silicone hydrogel lenses**[980]. In contrast, it was found that a switch from glasses **to soft contact lenses increased the progression of myopia** substantially, also adding a greater change in near-point phoria and a steepening of the corneal curvature[981].

Walline et al. reported[982]: "The RGP wearers' myopia progressed less than that of the SCL [soft contact lens] wearers. The **corneal curvature of the SCL wearers steepened more than that of the RGP wearers**, but the **axial growth was not significantly different** between the groups."

Jiminez R et al. stated[983]: "The higher accommodative lags found in this study with SCL could indicate that **prolonged use of SCL in near tasks may provoke a continuous hyperopic retinal defocus, a risk factor for the onset and progression of myopia**, as indicated in numerous studies."

The amount of oxygen transmitted through the lens appears to have an impact, too, als Blacker found[984]: "… **low-Dk/t hydrogel contact lens wearers [myopia] increasing more** during the study."

As an explanation for the inconsistent results, flaws in the design of the studies were made responsible[985].

In a summary of randomized controlled trials no evidence of positive effects of contact lenses (RGP) were found[1030] (see section 3.27).

The **potential positive effect of hard / rigid contact lenses** might be attributed to several different mechanisms:

Image quality and contrast are better with hard contact lenses than with soft lenses[410]. Correspondingly, substantial aberrations[986] were found at soft contact lenses. Poor image quality and poor contrast are correlated with the appearance and progression of myopia (see section 3.3).

Note:
*Is this the reason for **the missing positive effect of soft contact** lenses on the progression of myopia?*

A flat fitted lens can **flatten the cornea** (see section 3.26.2). It was stated that the positive effect of contact lenses cannot be explained by a flattened cornea only[987, 988]. In an individual case, it was found that an orthokeratology lens (see section 3.26.2 about orthokeratology), which was worn on one eye only, resulted in a substantially reduced increase in axial eye length[989]. In other words, the hard contact lens reduced the progression of myopia by other effects than the flattening of the cornea.

Note:
*Older hard contact lenses had a very low oxygentransmission, and to supply the cornea with sufficient oxygen the lenses were fitted rather or even highly flat. This flat fitting is no longer done with the RGP, because the oxygen supply is sufficiently achieved through the lens itself. The old flat fitted lens has a **similar effect as the lenses for orthokeratology, which appears to have a positive effect on the progression on myopia** (see section 3.26.2)*

Wearing **glasses results in less accommodation** compared with a normal eye, or compared with wearing contact lenses[206].

It was said[235] that already Bates (see section 3.2.2) hinted at a connection between chronic visual problems and a lack of blinking. Wearing hard contact lenses **promotes blinking** by the slight irritation.

The optics of some RGP outside the optical zone in the center might be working similarly as the dual-focus lenses mentioned in section 3.3.11. The very large variety of the optics of the various RGP lenses might be a reason of the conflicting results about the effectof RGP on myopia progression.

Maybe the minor, but permanent irritation of the hard contact lens causes an **increases blood circulation**. Increased blood circulation was made responsible for the positive effect on myopia (see section 3.17), but in the literature this effect of hard contact lenses was not claimed to cause the positive effect myopia.

Note:
Maybe the fact that newer designs and materials of hard contact lenses are less irritating, can explain the result of a study[977], which found no positive result of hard contact lenses on the progression of myopia. ***Potential argument: less irritation results in less blinking, which results in a steeper increase in myopia***

The corneal surface, which is optically improved by the hard contact lenses, can cause **fewer aberrations**. See section 3.3.9 about the interaction between aberrations and myopia.

Hard contact lenses can correct **astigmatism** up to a rather high degree. Whether astigmatism causes myopia appears to be not yet finally decided (see section 3.5).

The transition to contact lenses has some impact on the **AC/A ratio** due to the higher accommodation, and due to an eliminated prismatic effect of the glasses[468] (see sections 3.5.2 and 3.5.4). These effects, however, are identical for hard and soft contact lenses.

Rigid contact lenses might reduce the amount of **spherical aberration,** which can have an impact on myopia. For hard orthokeratology lenses Kang P stated[990]: "… study confirms that with OK treatment, the peripheral retina experiences myopic defocus, which is conjectured to underlie the observed slowing of myopia progression." (see section 3.3.9)

Note:
In contrast to today earlier versions of hard contact lenses were made of material with very low oxygen transmission, and therefore they were fitted very flat to enable sufficient oxygen supply. This makes them very similar to the orthokeratology lenses, which are discussed in section 3.26.2. Here might lay the explanation for the fact that the positive effect of contact lenses on myopia was reported preimarily at a time when these old materials was used.

Note:
Contact Lenses and plus glasses for extensive near work *appear to be a useful combination.*

Contact lenses are necessary when there is a **substantial difference in the refraction of both eyes**, because with glasses the difference of both images on the retina is too large to result in one combined image (see also section 3.30.8 about amblyopia).

Finally, yet importantly, switching from glasses to contact lenses might enhance the self-esteem substantially, especially for children and older girls.

For more information about contact lenses see section 4.2.

For Contact lenses with peripheral defocus or multifocal features see section 3.3.11

3.26.2 Orthokeratology / Overnight Corneal Reshaping (OCR)

(General sources[991, 992, 993, 994, 995])

If the base radius of the contact lens (see section 4.2.5) is substantially larger than the radius of the cornea of the eye, the lens is said to be fitted flat, and will cause the cornea to change towards the flatter shape of the contact lens. As a flatter cornea has less refractive power it can compensate for a low-grade myopia. Decreases of typically 1.0 to 2.0 D can be reached, but a limit of up to 7.0 D was reported[996] as well, which might be enough for many people to do without glasses or contacts lenses.

As the flattened cornea will go back to its original shape over time, the procedure has to be regularly repeated, i.e. for a lifetime, it you want to preserve its effect.

Bulimore et al. explained the mechanism of orthokeratology[995]: "Rather, **orthokeratology flattens the central area of the cornea** thereby providing a clear image on the central retina, while the **mid-peripheral cornea is steeper, imposing myopic defocus on the peripheral retina**. There is compelling evidence that **peripheral refractive error is important** in the incidence and progression of myopia. While myopic eyes have excessive axial length, they also have a more prolate shape as the eyes have grown longer axially than equatorially. **As a result, myopic eyes tend to have more hyperopic peripheral refractions**, compared with their foveal refractive error … Several subsequent studies have confirmed that reshaping of the cornea with **orthokeratology converts relative peripheral hyperopic defocus before treatment to relative peripheral myopic defocus** afterorthokeratology."

Reports about a permanent benefit of orthokeratology:

In an individual case, it was found that an orthokeratology lens, which was worn on one eye only, **resulted in a substantially reduced increase in axial eye length**[989]. In other words, the hard contact lens **reduced the progression of myopia by other effects than the flattening of the cornea**.

Similar results were obtained by comparing an orthokeratology group and a control group, as Kakita T reported[997]: "The increase in axial length during the 2-year study period was 0.39 ± 0.27 mm and 0.61 ± 0.24 mm, respectively, and the difference was significant."

Similarly, positive results were obtained by Cho et al. who measured the axial length of the eye and found a reduced in crease in lenght[993]. They found, however[998], "there are substantial variations in changes in eye length among children and there is no way to predict the effect for individual subjects."

Walline JJ et al. reported[999]: "The corneal reshaping group had **an annual rate of change in axial lengths that was significantly less than the soft contact lens wearers** (mean difference in annual change = 0.16 mm, p = 0.0004). Vitreous chamber depth experienced similar changes (mean difference in annual change = 0.10 mm, p = 0.006)."

Walline JJ, Holden BA et al. summarized the results[1000]: " While corneal reshaping contact lenses are effective at temporarily reducing or eliminating myopia, claims about the progress of myopia being controlled with corneal reshaping contact lenses should not be made until further studies are published in peer-reviewed literature."

Cho P and Cheung SW reported[1001]: " On average, **subjects wearing ortho-k lenses had a slower increase in axial elongation by 43% compared with that of subjects wearing single-vision glasses.** Younger children tended to have faster axial elongation and may benefit from early ortho-k treatment."

For hard orthokeratology lenses Kang P stated[990]: "… study confirms that with OK treatment, the peripheral retina experiences myopic defocus, which is conjectured to underlie the observed slowing of myopia progression."

As of 2014, a reduction of myopia progression by orthokeratology of between about 30% and 60% war reported[127].

It was emphasized, however, that beyond some indications that orthokeratology might slow the progression of myopia, the advantage of it might be twofold, as Reim stated[1002]:

- "Most patients who drop out of GP lens wear do so because of discomfort. Sleeping with the lens on the eye dramatically reduces lid interaction to the point where comfort has not been a problem."
- "... good distance vision after lens removal and no correction required during the day. This is the major reason why adults choose orthokeratology, and it is a very compelling point for active adolescents."

This is in contrast to another publication by Tsukiyama[1003]: "Overnight orthokeratology lens wear alters the anterior corneal shape rather than the posterior radius of the corneal curvature and the anterior chamber depth. This finding suggests that the primary factor in the refractive effect of orthokeratology is change in the anterior corneal shape rather than overall corneal bending."

Li et al. published a meta-analysis and found that the effect of orthokeratology is not just based on the flattening of the cornea[1004]: "At 6 months, 1 year, 1.5 years and 2 years, mean differences in axial elongation were -0.13 mm, -0.19 mm, -0.23 mm, and -0.27 mm ($p < 0.01$), respectively. The effect was greater in Asian children than Caucasian (-0.28 mm versus -0.22 mm) and in

children with moderate to high myopia when compared to children with low myopia (-0.35 mm versus -0.25 mm)."

As of 2015, a meta-analysis of seven studies came to the result that myopia progression was reduced by about 45%[1005].

Cho P et al. summarized[1039] : "… it appears that children **who discontinued orthokeratology treatment resumed the progression rate of myopia** that they would likely have demonstrated if they did not receive orthokeratology treatment."

A report warned that overnight wearing of orthokeratology contact lenses might be harmful in children[1006].

In more detail, an epithelial thinning in the center and a thickening at the edge is causing the refractive changes[1007].

Additionally it was reported that the optical quality of the cornea is degraded by orthokeratology, i.e. that astigmatism and higher order aberrations are increasing[1008]. Hiraoka et al reported[1009]: "**Orthokeratology significantly increases ocular higher-order aberrations and compromises contrast sensitivity function**, depending on the amount of myopic correction." (See section 3.3.9 about the effect of aberrations on myopia.)

Kwok et al. summarized[1010]: " It is noted that the physiological and biophysical bases of orthokeratology are virtually unknown, and further research on the human cornea is indicated to scientifically establish the safety of orthokeratology. Prospective patients, and their parents in the case of children, should be fully informed of the risks." Additionally, Walline et al. warned[1011]: " While corneal reshaping contact lenses are effective at temporarily reducing or eliminating myopia, claims about the progress of myopia being controlled with corneal reshaping contact lenses should not be made until further studies are published in peer-reviewed literature."

Paune et al. found[1012] "Smaller BOZD [back optic zone diameter] … slows AL [axial length] elongation better than standard OK [orthokeratology] lenses."

Loerthscher et al reported[1013]: "We conclude that MOK [multi focal orthokeratology] lenses significantly reduce eye growth compared to conventional OK lenses over 18 months."

Note:

So far it was assumed that orthokeratology works mainly by flattening the cornea transiently. These results by Paune and Loertscher, however, are either

- indicating that optical issues are playing an important role as well. This is astonishing as these lenses are worn at night with hardly any optical signal, or

- showing that a simple spherical flattening of the cornea is inferior to a curve which is taking care of peripheral defocus (see section 3.3.11.1).

Besides this there appears to be a substantial rebound effect of orthokeratology (see section 3.27.3).

Wang et al. reported about experiments with children, which used orthokeratology for 12 months[1014]: "… only greater SE (spherical equivalent, i.e. higher degree of myopia) and greater increase of CLT (crystalline lens thickness) were associated with smaller increases of AL in multivariable analyses."

Ding et al. reported[1015]: "… **improved accommodative accuracy** were observed during OK treatment, but **began to regress after the cessation of OK**. A significant positive correlation between improved accommodative accuracy and slowed axial elongation **was only observed during the first 6 months of treatment.**

Note:

If orthokeratology really reduces the progression of myopia, then "normal" contact lenses, which are fitted very flat, might have a similar effect.

Swarbrick, Alharbi et al. however, compared this effect of normal gas permeable (GP) lenses and orthokeratology lenses (both used over night) and found that the GP lenses had no effect on preventing myopia progression[1016].

3.26.3 Orthoculogy

For mild cases of myopia, it was claimed that by wearing flat contact lenses for about two minutes a re-establishing of distant focus could be achieved.

Yee stated in a hypotheses-paper[1017], "… it can be demonstrated that in cases of mild myopia, it is mainly due to the myopic or "bulged" shape of the crystalline lens." and "The stimulation activates a neuromuscular response to alter the curvature of the crystalline lens. After removing the contact lens, the crystalline lens would permanently "flatten" out accordingly to bring about distant focusing. The crystalline lens will still retain its ability to flex to a "bulged" shape for near focusing." and "With mild myopic cases, it is only necessary to attend to the crystalline lens."

Note:

Why should a short tem wearing of a flat contact lens have a different effect on the optical system than normal glasses? The flat lens will act as a low power minus lens, with the tear film acting as an additional minus lens.

3.26.4 Reinforcement of the Sclera

Some positive results for a reinforcement of the sclera were reported. The purpose of this treatment is, to place some support behind the sclera, and was done, e.g., by:

An **injection** with a polymer composition, containing copper-pyridoxine (i.e. containing copper and vitamin B6) was placed near to the sclera to promote collagen formation[844].

In a **surgical operation** the **synthetic material** mersilene was implanted, and a connective [1018]tissue capsule was built around it, with new collagen fibers growing through its cellular structure[1019].

In a **surgical operation** a **strip of the sclera from a donor eye** is placed around the eyeball to prevent further stretching[52].

It appears that these techniques are mainly applied in Eastern Europe, especially at the Helmholz Institute in Moscow, and more recently in China. There are, however, negative reports from other countries[1020].

People, which are very familiar with this technique, have published **very serious warning for these operations**[1021]. **Very serious complications include inflammations and infections, an increased internal ocular pressure (IOP), and changes of the muscular balance of the eye.**

Note:
It should be considered that there is hardly a fix in case an operation like this fails.

3.26.5 Acupuncture and Acupressure

Some moderate decrease of up to –1.0 D by acupuncture was reported[1022], and some success was reported for acupressure, too[1023]. In trials with laser puncture it was concluded that the positive effect is based on improvements of the accommodation / convergence system[1024]. Additionally, a positive effect on myopia development was claimed for infrasound ocular pneumomassage[1025].

Note:
Acupuncture depends to an extraordinary degree on the personal skill of the practitioner (and many people seem to work in this field with not necessarily this high qualification).

This reminds one of homeopathy: On one hand it seems to be esoteric, on the other hand there are numerous examples that homeopathy works in specific medical cases[1026].

A study to verify the benefits of acupressure could not confirm positive claims with respect to myopia[1027].

The industry offers equipment for a massage of the eye[1028], claiming positive effects on myopia without giving scientific proofs.

3.26.6 Electrostimualtion

One experiment reported that transconjunctival electrostimulation had positive effects on the accommodation, and slowed the progress of progressive myopia.[1029]

3.27 Summary of Randomized Trials to Slow Progression of Myopia

3.27.1 Single Trials

Walline et al. went through numerous medical dadabases to summarize randomized trials about the question, which treatment slows down the progression of myopia.

Their result[1030]: " **Undercorrection of myopia** [*note: permanent undercorrection*] was found to increase myopia progression slightly in two studies; children who were undercorrected progressed on average 0.15 D (95% confidence interval (CI) -0.29 to 0.00) more than the fully corrected SVLs wearers at one year. **Rigid gas permeable contact lenses** (RGPCLs) were found to have no evidence of effect on myopic eye growth in two studies (no meta-analysis due to heterogeneity between studies). **Progressive addition lenses** (PALs), reported in four studies, and **bifocal spectacles**, reported in four studies, were found to yield a small slowing of myopia progression. For seven studies with quantitative data at one year, children wearing multifocal lenses, either PALs or bifocals, progressed on average 0.16 D (95% CI 0.07 to 0.25) less than children wearing SVLs. The largest positive effects for slowing myopia progression were exhibited by **anti-muscarinic medications**. At one year, children receiving pirenzepine gel (two studies), cyclopentolate eye drops (one study), or atropine eye drops (two studies) showed significantly less myopic progression compared with children receiving placebo (mean differences (MD) 0.31 (95% CI 0.17 to 0.44), 0.34 (95% CI 0.08 to 0.60), and 0.80 (95% CI 0.70 to 0.90), respectively)".

For trials with soft contact lenses with positive progression on the outer circles, see section 3.3.11.

3.27.2 Comparisons of the Efficacy of the Various Measures to Slow the Progression of Myopia

a) As of 2015, Smith J et al. summarized the results of various sources in an extensive review[1031]: "**Of all the methods studied to slow the progression of myopia, topical pharmaceutical agents, orthokeratology contact lenses, and soft bifocal contact lenses were found to be the most effective, commercially available modalities**." Here, treatment with Atropine resulted in an average slowing

of myopia progression by 77%, for soft bifocals, this number was 48%, and for orthokeratology, the number was 43%.

b) The Brian Holden VISION INSTITUTE was publishing an Internet calculator[1032] by which the average progression of the myopia of a person with a specific age after using a specific measure can be calculated online.

Here an example for the myopia progression for a child with age 7 years and myopia of 1,00 diopters until age 17 years is shown:

- **No attempt of myopia control:** **- 6.72 D at age 17 years**
- High dose of atropine (1%): - 2.32 D
- Low dose atropine (0,01 – 0,05%): - 3.34 D
- Mulifocal soft contact lenses: - 3,92 D
- Executive bifocals: - 4.14 D
- Orthokeratology: - 4,26 D
- Progressive addition spectacles: - 5,06 D
- Peripheral defocus spectacles: - 5.75 D

c) Jinai Huang et al. summarized the results of numerous interventions to slow down the progression of myopia[1033] by calculating the mean differences in the reduced myopia progression per year **compared to single vision spectacles**:

- Atropine high (1% or 0.5%): 0.68 D (i.e. in average 0.68 D better than single vision spectacle lenses)
- Atropine moderate dose (0.1%): 0.53 D
- Atropine low (0.01%): 0.53 D
- Prismatic bifocal spectacle lenses: 0.25 D
- Peripheral defocus modifying contact lenses: 0.21 D
- More outdoor activities: 0.14 D
- Progressive addition spectacle lenses: 0.14 D
- Peripheral defocus modifying spectacle lenses: 0.12 D
- Bifocal spectacle lenses: 0.09 D
- Rigid gas permeable contact lenses: 0.04 D
- Soft contact lenses: - 0.09 D (i.e. in average 0.09 D worse than single vision spectacle lenses)
- Undercorrected single vision spectacle lenses: - 0.11 D

d) J Cooper[1034] summarized analyses by J Huang[1033] (meta analysis) and J Cooper[1035]:

Myopia pregression treatment	Effectiveness calc. by Huand	Effectiveness calc. by Cooper
Atropine high dosage	65%	85%
Atropine moderate dosage	65%	76%
Atropine low dosage	45%	60%
Orthokeratology	45%	45%
Multifocal soft contact lens	33%	40%
Progressive/bifocal glasses	12%	16%
Single vision	0%	0%
Under correction	-9%	-8%

e) Zhao et al. reported[1036]: "After oneyear, … participants aged ≤10 years were better controlled in the SA [spectacles and 0.01% atropine] in low-myopia group, **whereas those aged ≥11 years were better controlled in the OK [orthokeratology] in high-myopia group**."

C F. Wildsoet et al. published a very detailed description of numerous studies with the title "**IMI - Interventions for Controlling Myopia Onset and Progression Report**"[1037].

M A Bullimore published a summary "**Myopia Control 2020: Where are we and where are we heading?**"[1038]

3.27.3 Rebound Effects

Obviously, however, that for the various concepts to slow the progression of myopia **substantial rebound effects after discontinuation may exist:**

Cho P et al. summarized[1039]: "… it appears that children who discontinued **orthokeratology** treatment resumed the progression rate of myopia that they would likely have demonstrated if they did not receive orthokeratology treatment."

Ding et al. reported[1015]: "… **improved accommodative accuracy** were observed during OK treatment, but **began to regress after the cessation of OK** [orthokeratology]. A significant positive correlation between improved accommodative accuracy and slowed axial elongation was only observed during the first 6 months of treatment.

Chia A et al. summarized[939]: "There was a myopic rebound after atropine was stopped, and it was greater in eyes that had received 0.5% and 0.1% atropine. **The 0.01% atropine effect, however, was more modulated and sustained."**

Note:
It can be expected that only means which are applied "forever" or at least until adulthood will prevent progression of myopia.
Therefore it looks like that only mere optical plus additions etc. and environmental influences like time outdoors and maybe diet will have a permanent positive effect on the prevention of myopia progression.

3.28 Correction of Myopia by Surgery

The methods described here are those that change the refractive properties of the eye itself, in contrast to external devices like glasses, and traditional contact lenses.

Surgical techniques should be used only when the degree of myopia has stabilized.

Candidates of these treatments should be aware, however, that the result of the surgery will not be stable and the myopia will progress if the environemtal conditions which caused the myopia (like excessive nearwork) still persist.

3.28.1 Manipulation of the Cornea

3.28.1.1 Radial Keratotomy RK

(General sources[1040, 1041])

Radial cuts are made in the cornea to change the radius of the surface. The method is used to treat myopia in the range of – 2.0 to – 6.0 D. Potential problems: Due to a limited acuity of the new refraction, glasses or contact lenses might still be required. Glare at night can occur.

3.28.1.2 Photorefractive Keratectomy (PRK)

(General sources[1042, 734])

Removing corneal material by a laser reshapes the surface of the cornea. The method is used to treat myopia in the range of – 1.0 to – 6.0 D. Best results are achieved for myopia of up to – 3.5 D. Potential problems: Under- or over-correction can occur, but predictability is normally very good. Corneal haze can occur, and pain after the surgery is common.

3.28.1.3 Laser In Situ Keratomileusis (LASIK, Epi-LASIK), Laser Epithelial Keratomileusis (LASEK), Femto-LASIK

(General sources[957, 734, 1043, 122])

The difference from PRK is that before operating the laser a surface segment of the cornea is flipped aside after cutting it off from the side. After the reshaping procedure with the laser, this surface segment is flipped back, allowing a very fast healing and providing an undamaged surface.

Different versions of this procedure are:

In **LASIK,** the surgeon cuts a flap in the (deeper) stroma of the cornea (about 150 μm, i.e. 0.15 mm deep). After the surgery, the flap is put back in place.

In **Epi-LASIK** the surgeon cuts a flap in the epithelial layer of the cornea, similar as in LASIK, but to a depth of only about 50 μm (0.05 mm).

In **LASEK,** the epithelial layer of the cornea is rolled away by a swab wetted with alcohol. After the surgery, this layer will be rolled back again and covered temporarily by a contact lens.

In Femto-LASIK, the epithelial layer of the cornea is removed by a specific laser.

The cutting of the flap in LASIK can be done mechanical by a blade or by a laser[1044].

The method is used to treat myopia in the range of – 1.0 to – 12.0 D (or even up to – 15 D). Predictability is normally very good (the lower the myopia, the better the predictability), and the lower the myopia, the better the stability of the new refraction[1045]. Haze can still occur. Machet[1046] stated: "Just as the good can be very good, the bad can be very bad".

Waxler stated[1047]: "Unfortunately industry provided a biased accounting of adverse events resulting in a rate of 1.0% rather than 20.0% at six months post-Lasik."

For some hints before deciding on a surgery like this see section 4.3.

3.28.1.4 Small Incision Lenticule Exraction (SMILE)

Here by laser an internal disc within the cornea structure is isolated and afterwards removed. It is claimed that side effects of Lasik can be avoided as the surface of the cornea is not involved, and that the results of myopia corrections are stable[1048].

3.28.1.5 Intrastromal Corneal Ring

(General source[1049])

A plastic ring is placed under the surface of the cornea, making the curvature of the cornea more flat. The ring is inserted in two semicircles in two surgically prepared channels in the surface of the cornea. The thicker the ring is, the higher is the achieved correction of the refraction. The method is used to treat myopia in the range of – 1.0 to – 4.0 D (or even up to – 6.0 D). The procedure is reversible by taking the ring out, or changing it. Results are not always predictable[1080], but the long-term experiences appear to be positive[1050].

3.28.1.6 Artificial Cornea

(General source[1051])

An implanted biocompatible polymer might be used one day to modify the refractive properties of the cornea. Xie et al. stated[1051] that artificial corneas "…have the potential to become an alternative to spectacles and contact lenses for the correction of refractive error."

There are three different types of implants discussed: an implant that sits on the surface (i.e. replaces a segment of the epithelium, synthetic onlay), an implant that sits inside the cornea (i.e. in the stroma, synthetic inlay), and an implant, which replaces a full segment of the cornea (i.e. replaces a segment of the epithelium, the stroma and the endothelium).

3.28.2 Manipulation of the Lens System inside the Eye

(General source[1052], reports about early implants e.g. in 1986[1053, 1054])

There are four alternatives changing the refraction of the lens system inside the eye:

Removal of the biological lens

Exchange the biological lens

Addition an additional lens into the anterior chamber (i.e. in front of the iris)

Addition an additional lens into the posterior chamber (i.e. between iris and own lens).

There is quite a substantial risk of severe complications for these operations e.g. like retinal detachment, or decrease in lens transmittance[1055]:

"If today the only means available for correcting myopia consisted of [surgery] and tomorrow somebody invented glasses or contacts, he'd win the Nobel Prize hands down."[1056]

3.28.2.1 Exchange of the biological lens:

This surgery is similar to the common surgery for patients with a cataract and is done at refractions over – 10 D.

For older people successful posterior chamber implantation of multifocal intraocular lenses was reported[1057, 1058].

For patients with a cataract there are new reports about artificial lenses, which are able to accommodate in quite the same way as the original lens[1059]. The future will show, whether this will be an alternative for myopic patients, too.

3.28.2.2 Adding an additional lens:

The additional lens can be inserted either into the anterior chamber (i.e. in front of the iris), or into the posterior chamber (i.e. between iris and own lens). This technique is applied for refractions over – 8 D up to over – 25 D.

First results of these techniques were quite promising[1060, 1061, 1062] and favor the additional lens (IOL, intraocular lens) compared to the exchange of the lens (CLE, clear lens extraction)[1063].

It was said, that the main risk when using an implanted lens in the anterior chamber is that it might become loose and damage the back of the cornea, while the main risk when using an implanted lens in the posterior chamber immediately in front of the own lens is that the lens becomes blur and has to be removed[1064].

An analysis of studies between 1996 and 2004 about refractive lens exchange showed that the risk for retinal detachment was 1.85% compared to 1.5% of highly myopic people without surgery[1065].

Overall, **further trials are necessary and many surgeons are still hesitating[1066], on the other hand there are** .

When monofocal and multifocal intraocular lenses are compared, the optical quality favors monofocal lenses[1067].

There are new developments in the design of the lenses: for bifocal applications diffractive lenses were found to be superior compared with refractive lenses[1068]. Diffractive lenses are built by tiny microstructures on the surface of the lens; refractive lenses are like conventional lenses[1069].

3.28.2.3 Risk-comparison between LASIK and implantable contact lenses (ICL):

An analysis of the actual and the theoretical risks for implantable contact lenses for moderate to high myopia showed that the risk for visual loss by these lenses is even lower than for LASIK or PRK[1070, 1071].

Note:

On the one hand, these operations are rather similar to standard and low-risk operations in ophthalmology, on the other hand, every operation is carrying some risk of infection, and additionally there is the serious general risk of long-term effects. These long-term effects are not so important for older cataract patients, but are especially important for young patients.

3.28.3 Enforcing the Sclera

X Dong et al. reported[1072] about the efficacy of modified Snyder-Thompson posterior scleral reinforcement round **scleral patches** in Chinese children with high myopia: "Results: AL [axial length] had increased by 0.29 ± 0.33 mm in the PSR [posterior scleral reinforcement] group and 0.82 ± 0.33 mm in the control group at the final follow-up. The change in the SE [spherical equivalent] was 0.31 ± 0.81 D in the PSR group and 2.25 ± 1.02 D in the control group."

3.29 A Few Recommendations

Some results of the research about **image quality, accommodation and related issues**[1073], [1074] are summarized in Table 9:

For near work keep a reasonably large distance to your book / paper / computer screen, even when wearing plus additions. ***Note:*** *Reading in bed leads mostly to a distance, which is too near.* **Do not use glasses or contact lenses, which are stronger than necessary,** i.e. avoid any over-correction**.** You might use "main glasses / contact lenses" which are slightly under-correcting and you use additional glasses for perfect distant vision. **Even if you are not myopic yet, better use plus glasses for extensive near work.** **If you are already myopic, use bifocal or progressive glasses or bifocal contact lenses, or use plus glasses additionally to your contact lenses for extensive near work.** **Interrupt your near work** every 30 minutes by focusing on distant objects and **relax your eyes especially in the evening before going to sleep.** **Wearing plus glasses for a short time every day may be of some help.** **BASIC PRINCIPLE: avoid degraded image quality, and avoid longer time / excessive accommodatio** **Cold-color light** should be preferred to warm-color light. **Do not read and don't do near work at bad light, 500 Lux** are the minimum, but substantially higher levels are recommended depending on the visual task (e.g., for detailed drawing work 1,500 to 2,000 lux). Some **exercising of the accommodation** by alternating focusing near and far objects can be helpful (but don't expect miracles from classes which are offered about this issue). **Take care to have enough sleep at the proper time and in darkness.** Do not keep a light switched on in the kid's room at night (there is a controversy in the literature about night lights, but better be on the safe side). **Perform regular physical exercises, preferably outdoors,** and **use sun-glasses in rather bright sunlight only** **Take care of getting enough vitamin D** (see section 3.24) and consider Riboflavib (see section 3.24.15.1)	No risk, **but avoid a permanent and substantial undercorrection** without the consultation of an ophthalmologist, as an inappropriate undercorrection or inappropriate bifocals may create, e.g., a deprivation effect[202].
Discuss with your ophthalmologist the application of **atropine drops**. Consider **rigid gas permeable contact lenses** (RGP). Soft contact lenses were not reported to show a positive effect, but soft **bifocal contact lenses showed a positive effect**, too. Consider **orthokeratology.**	None if properly and professionally applied.

Table 9 A Few Recommendations

Similar recommendations were published by the government of Singapore in the Internet[1075].

Note:

Science confirms now some old and basis ideas of Bates and Wiser mentioned above. It does not confirm, however, the exaggerated promises of some of the followers, i.e. to reverse myopia

3.30 Summary: What Causes Myopia?

Three main mechanisms appear to lead to myopia:

Optically initiated effects, including some effects caused by accommodation. These involve some so far in detail unspecified biochemical processes. The normally balanced eye growth of childhood (emmetropization) doesn't occur.

Mechanical effects, including effects caused by accommodation, which enforce an elongation of the eyeball – in connection with an unfortunate geometry and weak connective tissue.

Systemic connective tissue degrading processes, which are sometimes rather pathologic, and which often appear to have a genetic reason.

All the other mechanisms, given above as potential causes of myopia, are possibly using various sub-mechanisms of one of these processes, and may take place simultaneously.

Near work and accommodation apparently play a key role in the development of myopia. However, not everyone is affected by these factors. Therefore other processes must be very important as well. These processes are obviously playing a big role in progressive and in pathologic myopia.

Maybe all the pathways mentioned above are biochemically or logically **combined, e.g.:**

Optical effects might in fact result in **connective tissue degrading** effects to remodel the shape of the eye.

Mechanical effects might induce transient **optical blur**, cause over correction, and cause myopia by these **optical effects**.

Mechanical effects might cause **connective tissue degrading effects** (e.g. via temperature or by simple stretching).

Consequently, preventing myopia or stopping the progression of myopia might be achieved one day by interrupting the (sometimes rather long) sequence of biochemical process-event-steps, which finally lead to modified or degraded connective tissue structures in the eye.

This can only be done in one of the following ways:

Modify **personal behavior and/or environment**.

Modify **nutrition**.

Make a **massive pharmaceutical intervention**.

The advice resulting from personal behavior were referenced already in section 3.15 and section 3.26.1.

Finally, it should be remembered (see section 3.19.2) that there are reasons that via biochemistry myopia is linked to the personality of the myopic person, which cannot be handpicked, either. **And if you are happy with your personality, you might consider myopia as a price to pay for it.**

3.30.1 School and Myopia

The simple, non-pathologic, non-progressive form of myopia is sometimes called school myopia. According to the results presented above schooling may, however, have some basic influences on myopia, which might play a role for progressive myopia, too.

Being a student implies a lot of **near work** and accommodation, and additionally a **frequent change** between near work and viewing the writing on the distant blackboard. This environment, together with the **hysteresis of accommodation, of the ocular shape and even of the ocular lens** (see section 3.7) can result in children being unable to read the blackboard properly, and they will get glasses. This **cycle may repeat and repeat**, resulting in a progression of myopia.

Depending on the personality of the child, and of the performance requirements set by the school, the child may be **stressed by educational requirements**; for the impact of stress on myopia see section 3.19.

3.30.2 Is Myopia Caused by Mechanical or by Biochemical Processes?

It looks like that there can hardly be a compromise between the proponents of a completely mechanical explanation ("accommodation-forces are responsible") of myopia and the proponents of a completely biochemical explanation ("image quality is responsible", "genetics are responsible", "nutrition is responsible").

There is, however, a linkage between the two kinds of explanation: mechanical forces initiate biochemical changes, a process called **mechanotransduction**, which was already discussed for explaining the development of myopia[346].

This model was supported by the result that **scleral fibroblasts, which were mechanically stretched, showed significant changes in gene expression**[186].

Notes:
Together with the fact that accommodation generally results in a temporary elongation of the eye (see section 3.2.1.1) this impact of mechanical strain on gene expression and herewith on biochemical processes could alone explain a development of myopia.

The biochemical argument received a strong support by these linkages, and dopamine appears to be a key component:

Time spent outdoors is positive to prevent the onset of myopia (see section0)

🡻

Time spent outdoors increases status of vitamin D and level of illumination (see section 3.24.3 about vitamin D and section 3.14.1 about the level of illumination).

🡻

Vitamin D and sunlight increase the level of domamine (see sections 3.3.3, 3.24.3 and 3.24.4)

🡻

Dopamine has a positive impact on the onset and the progression of myopia (see section 3.3.3)

3.30.3 Is Myopia caused by Mechanical or Optical Processes – are Saccades a Linkage?

The main conflicting opinions are "myopia is caused by excessive near work and the resulting mechanical stress" and "optical fucusing effects trigger signals on the retina which cause myopia". No compromise appears to be possible.

A proposal for an explanation:

Near work and a low level of illumination as well as glucose metabolism can cause faulty accommodation by badly coordinated saccades (see section 3.6)

🡻

Faulty accommodation (accommodation lag etc.) means not only delayed or inaccurate accommodation but also repeated attempts of over-accommodation.

🡻

Faulty accommodation results in signals to the retina indicating reduced image quality, which again tries to correct the accommodation.

🡻

Excessive accommodation attempts means muscular overload and inflammation accompanied by degradation of connective tissue (see section 3.18.2).

3.30.4 Prevention of Progression of Myopia or Prevention of Myopia?

The progression of myopia is fought with the same tools that prevent it in the first place.

Generally it is very difficult, however, to convince people (especially children) to take action **before** a problem appears. It is the more necessary to take this prophylactic action if there is a problem of myopia already in the family.

Schaeffel summarized[1076]:

"From extensive research in recent times, three major approaches have emerged to interfere with myopia progression in children:

(1) promoting exposure to bright light and enforce outdoor activity,

(2) adapting/improving optical corrections and visual behavior [i.e. avoid excessive accommodation during near work] to generate inhibitory signals for eye growth in the retina, and

(3) applying atropine eye drops at low doses."

3.30.5 Working against Myopia or against the Consequences of Myopia?

The proposed means can work to stop the progression of myopia, e.g. by stabilizing the degraded connective tissue, but they can also be helpful in preventing the serious consequences of higher grades of myopia (which were mentioned in section 1.7).

This prevention of consequences is in fact the most important issue, considering the tragedy of a potential blindness!

3.30.6 Functional- versus Structural- Deficits

Structural defects can be responsible for more severe myopia, i.e. the process of viewing and focusing is working normally, but the structure of the tissue is degraded. Alternatively, myopia can be due to **functional defects**, i.e. the structure of the tissue is normal, but the process of viewing and focusing is not working normally.

To be more specific, there can be these cases:

Structural deficits alone (e.g. Marfan syndrome)

Functional deficits alone – they can be **optical** (e.g. heavy esophoria at near) or **biochemical** (e.g. an exaggerated feedback loop of image related effects, see section 3.3)

Structural deficits cause additional functional deficits (e.g. degraded connective tissue results in decreased stability of the sclera and decreased performance of the ciliary smooth muscle)

Functional deficits cause additional structural deficits (e.g. form deprivation experiments cause degraded connective tissue)

A third reason causes both structural and functional deficits (e.g. **mental stress** with all its implications: degraded connective tissue, accommodative spasms etc.)

Note:
It appears to be logical that

*- **for functional** deficits optical means are most appropriate (at least until there are means to control the feedback loop of image related effects)*

*- **for structural deficits systemic means, i.e. via nutrients are most appropriate**. Structural deficits are probably the major reason for progressive myopia and pathological myopia.*

The mental issue can have a very strong impact on myopia (see section 3.19), and **mental conditions can influence functional processes as well as processes which may lead to structural problems.**

3.30.7 Is Myopia Inherited or Acquired?

This question was raised already in section 2.1. The results of this section, together with the results discussed in section 3.3.5 ("Emmetropization" towards Myopia) lead to the summarizing statement:

Except for some few rather pathologic cases myopia is not inherited, it is the emmetropization factor, which is inherited.

In other words, it is mostly the strong interaction between the personal "old" genetic heritage and the "new" environment, which leads to myopia.

A writer in the Internet expressed this as follows[1077]:

"Genes are always a factor of our health, but that is the only factor we can't do anything about. Genes only represent our predisposition & potential to encounter certain problem or disease. It is our life and our lifestyle as whole that makes the final decision on whether we are going to experience certain problem or not."

Viikari has expressed this in other words[41]:

"By mean of suggestion, belief in hereditary factors has probably been the most harmful influence of all. What is indeed inherited is a set of general reactions to life's situations, including spasm of accommodation."

Finally, it has to be repeated from section 2.1 what Verhoeven VJM reported[114]: "Individuals at **high genetic risk in combination with university-level education had a remarkably high risk of myopia** (**OR 51.3**; 95 % CI 18.5-142.6), while those at **high genetic risk with only primary schooling were at a much lower increased risk of myopia (OR 7.2**, 95 % CI 3.1-17.0)." [OR = Overall Risk, CI = Confidence Interval]

When talking about genetic inheritance, one has to talk at the same time about nutrition and environment.

This can be summarized as:

Inheritance counts only in so far, as a sensivity or insensitivity towards environmental influences is inherited.

Research results gave a proof for this, as Parry for Mail Online summarized[1078]:

"They found **people with a certain variant of the gene - called APLP2 - were five times more likely to develop myopia in their teens if they read for an hour or more each day as a child. … those who carried the APLP2 risk variant but spent less time reading had no additional risk of developing myopia**."

3.30.8 Congenital Myopia, and Inherited Diseases which are related to Myopia

There are two possible explanations for myopia at birth (**congenital myopia)**:

Without any pathologic biochemical malfunctioning **the eye can be simply too long already at birth** – according to the observed phenomena of large variations in size and shape of all kind of organs[524]. If the deviation from the normal length is too large, emmetropization can hardly fix it.

Open question: Will myopia progress in this case?

Amblyopia is a reduced visual acuity without visible pathologic defects. In most cases one eye only is affected. The affected eye is often highly myopic, which is named anisometropic amblyopia. To prevent the handicapped eye from being switched off the therapy consists generally of a part time occlusion of the well functioning eye (penalization), or of a treatment with Atropine[1079]. This switching off of one eye is often achieved also by the use of atropine eye drops. Unequal contact lenses need to be used if the handicapped eye has myopia of more than about 4 diopters, as glasses result in images of too different size on the retina.

Note:

It appears to be quite open, whether the myopia of the handicapped eye is caused by the amblyopia itself (according to optical effects described in section 3.3), or whether the congenital one-sided high myopia causes amblyopia.

Severe biochemical malfunctioning is already present – malfunctioning which often shows symptoms other than high myopia. Most of these diseases are affecting the connective tissue. A number of these defects have been described (overall there are more than 150 genetic defects which are related to myopia[99] and related degraded connective tissue:

- **Stickler's syndrome**, accompanied by bone, heart, ear and eye problems (besides myopia affecting vitreous body, retina, focusing, glaucoma), but usually patients do not have all the problems. Houchin stated[1080] that Stickler's syndrome "is believed to be the most common syndrome in the United States and Europe, but one of the rarest to be diagnosed". Children with Stickler syndrome have a depressed nasal bridge, short nose and joint hypermobility[1081].

  Note:

  These features remind of the features of many Asians, and Asians have substantially elevated rates of myopia.

- **Marfan's syndrome**, accompanied by extreme mobility of the joints, dislocations of the lens of the eye, and heart problems.

- **Mitral valve prolapse (MVP)**, a heart problem, which is considered to be a generalized connective tissue problem. It is accompanied by an elevated rate of myopia (can be caused by Marfan's syndrome, but does not have to be caused by it)[1082].

- **Barlow syndrome** / mitral valve prolapse syndrome (a mild form of the Marfan's syndrome?), accompanied by heart problems, and extreme mobility of the joints.

- **Ehlers-Danlos syndrome**, accompanied by accompanied by extreme mobility of the joints, osteoporosis, and ruptures of blood vessels.

- **Kearns-Sayre syndrome**, accompanied by paralyzed muscles of the eye, and heart problems.

- **Seckel syndrome**, accompanied by reduced growth and pigmentary retinopathy.

- **Cohen syndrome**, accompanied by psychomotor retardation and hyperextensibility of the joints.

- **Prader-Willi syndrome**, a genetic human obesity syndrome.

- **Nystagmus**, i.e. uncontrolled, often rhythmical movements of the eyeball. Nystagmus can be congenital or develop at a later time. Nystagmus was correlated to a deficiency in B vitamins (see section 3.24.15) and Magnesium (see section 3.24.4).

- **Homocystinuria**, i.e. an elevated level of homocysteine (see section 3.24.17).

- **Celiac disease** which degrades the connective tissue.

- **Ptosis or Blepharoptosis**, an uncontrolled hanging down or drooping of one or both eyelids. There is, as Gusek-Schneider found "an overall higher frequency of myopia in human ptosis ... in unilateral ptosis, a higher frequency of myopia in the ptotic, than in the fellow eye."[1083] The rates of astigmatism and amblyopia are increased as well. While it appears to be open what causes the ptosis in the first place (e.g. a defect of the local nerve system, a weak local connective tissue, a local muscle problem), the resulting myopia was attributed to the optical effect of deprivation[1084] (see section 3.3). Therefore, a fixing of the lid position appears to be of top priority[1085].

As can be seen above, a **hypermobility of the joints**, which is based on a connective tissue problem frequently accompanies inherited myopia.

The result of a study about students in Turkey was that myopia is slightly more common among students with hypermobility[1086].

Note:
The degree of myopia of the students with hypermobility was not investigated in this study – it would be plausible if the degree of myopia of the students with hypermobility is higher than that of the other students.

Prematurity as another cause for myopia[1087] has to be mentioned here, even as prematurity can not really be described as a congenital issue.

Until more research results will be published, **the best that can be done** in all these cases appears to be to follow overall recommendations which are given e.g. in this book. The malfunctioning biochemistry is unlikely to be exactly corrected, but hopefully some counterbalancing mechanisms can be activated. In this way, some degree of help may be found to correct the negative biochemistry. **At least it is worth trying!**

The syndromes mentioned above are describing **some very distinct diseases**. Far more often there are **just some deviations** from the "normal" status or from "normal" biochemical functioning, which has as one of its consequences the appearance of myopia. **Often this specific biochemical process is inherited, but it can be as well be caused during pregnancy or by the circumstances of the birth**. **Alternatively, some behavior, habit, or nutrition at a later age simply does not match with one of these biochemical processes.**

Therefore, pathological myopia can be considered as always congenital, in a certain way.

Note:

The reason for cases of congenital myopia does not always have to be a degraded connective tissue, which affects the sclera; it can be as well a metabolic defect which causes an exaggerated feedback process which is triggered by an image-quality-effect as outlined in section 3.3.

3.30.9 From Simple to High and Progressive Myopia

In principle high and progressive myopia can have to two origins:

- An already from the beginning degraded and weak connective tissue which causes the eye to stretch and elongate, independent from optical or muscular influences
- Optical and/or muscular influences caused "simple" myopia, stretching herewith the eye. When the connective tissue of the eye is already in a somewhat less stable condition than average this stretching might be the entry into further stretching, i.e. progressive myopie.

Conclusion: Especially if there is an indication of an inherited degraded connective tissue or a myopia in the family it is the more important to use all the available means to prevent the onset of myopia right from the beginning.

3.30.10 Summary of the Summary: Are the Published Results really Contradictory? Maybe not!

Maybe the published results about the reasons for myopia and its progression are not as contradictory as they seem. Maybe the following personal view (which might have been expressed by other people before as well) explains many (not all) of the published results:

During accommodation the eye is **squeezed by the ciliary muscle in transverse direction, and as a consequence elongates via the hydraulic intraocular pressure IOP** (see sections 1.3.2.4, 3.7.6 and 3.7.2).

Poor **image quality leads to a local degradation of the connective tissue**, which allows remodeling of the ocular shape (see section 3.3.2). Possibly this remodeling is caused via tissue-turnover-regulating processes, and mechanisms that involve processes of the immune system.

Both effects, an increased pressure in the direction of elongation, and a biochemically-weakened structure work **in the same direction: myopia**. Moreover **mechanical stress can initiate biochemical alterations via a process called mechanotransduction.**

Other observed influences, e.g., the impact of **mental stress, illumination, and weaker inborn connective tissue** support the mentioned basic effects of pressure and local tissue degradation. Obviously myopia is correlated with lower amplitude / lag of accommodation (section 3.2) and

with a somewhat degraded connective tissue. **A softer relaxed ciliary muscle, and softer zonular fibers result in less tension for pulling the lens into the flat distant-focus shape**.

An important key word about all these potential mechanisms is **emmetropization**, i.e. the ability of the eye to adjust the eye-growth in length during development for optimal optical imaging – with a corresponding myopic adjustment if near focus is a major environmental requirement. Combined with the tissue degrading effects found at experimental myopia it could be concluded that **near work might control eye growth through tissue degrading effects**. Consequently, a **strategy to prevent (progression of) myopia should improve near work conditions, and/or tissue degrading biochemical conditions** (i.e. to reduce what is called in section 3.3.5 the "emmetropization factor").

K. Viikari expressed her lifelong experience as an ophthalmologist that eye problems are frequently systemic problems of the whole body and mind in these words[1088]: "Prevention of myopia has a very central position in it but the accommodation event, through the nervous system, covers all of our bodily functions. Shortly said the whole of our well-being and hence **there is no branch in medicine which does not have something to do with eye stress.**"

As a consequence, the most important tools to prevent onset and progression of myopia would be:

Reduction of accommodative and convergence stress e.g. via reading with appropriate distance only or via appropriate undercorrection for reading. Wearing plus glasses for a few minutes a few times per day can block the onset of myopia (see sections 3.4 and 3.19).

Maintain a permanent good image quality, e.g. via good illumination, and by proper correction for distant viewing. Avoid long-term undercorrection with respect to the respective viewing distance.

Strengthening of the connective tissue, e.g. via optimized nutrition which helps to prevent degradation, which might be caused by local effects (e.g. via poor image quality) or by systemic processes.

Outdoor activities can compensate for accommodative stress, can contribute to a sufficient supply of vitamin D, and, e.g., the outdoor illumination can have a positive effect on the day-night rhythm and the **outdoor UV-light can strengthen the sclera**.

Physical exercises help to reduce stress, increase blood circulation and NO metabolism.

Keep a healthy sleep-time / wake-time rhythm.

The optical aspects of these advices are summarized in Figure 14

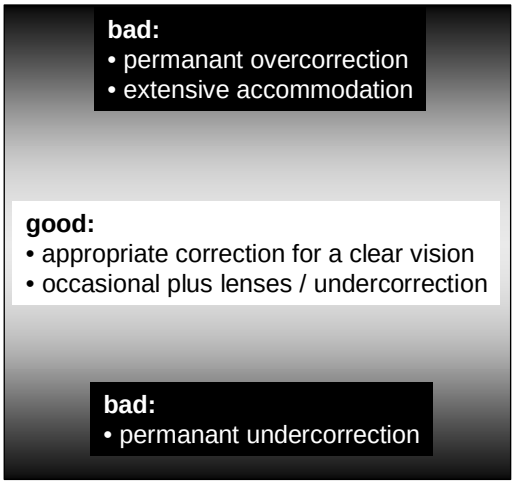

Figure 14 Summary of advices for optical correction

According to this model, the development of myopia can be simplified as shown in Figure 15 and Figure 16.

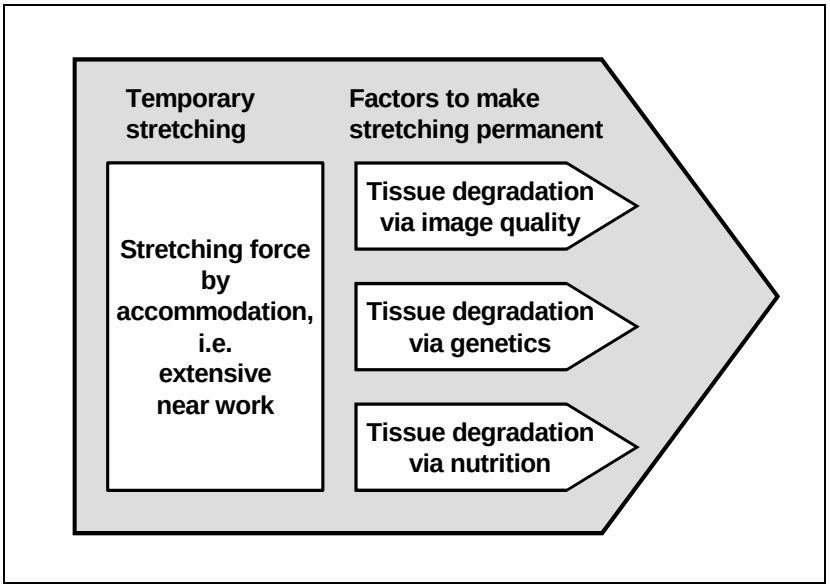
Temporary stretching
Factors to make stretching permanent
Stretching force by accommodation, i.e. extensive near work
Tissue degradation via image quality
Tissue degradation via genetics
Tissue degradation via nutrition

Figure 15 The process of myopia development - very simplified

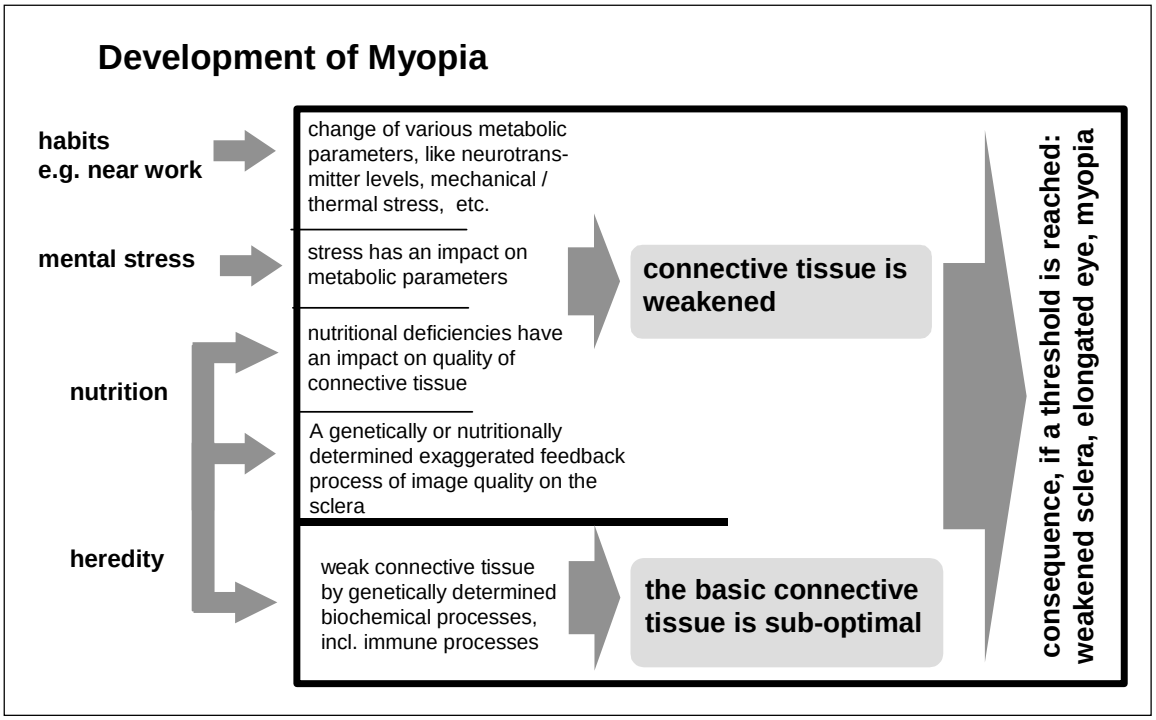
Development of Myopia
habits
e.g. near work
mental stress
nutrition
heredity
change of various metabolic parameters, like neurotrans-mitter levels, mechanical / thermal stress, etc.
stress has an impact on metabolic parameters
nutritional deficiencies have an impact on quality of connective tissue
A genetically or nutritionally determined exaggerated feedback process of image quality on the sclera
weak connective tissue by genetically determined biochemical processes, incl. immune processes
connective tissue is weakened
the basic connective tissue is sub-optimal
consequence, if a threshold is reached: weakened sclera, elongated eye, myopia

Figure 16 The process of myopia development – more detailed

Fig. 15 can be summarized as well with respect to the emmetropization factor, which was mentioned in section 3.3.5 and which determines the onset and the progression of myopia:

Optical hygiene, i.e. the prevention of excessive accommodative load and of reduced image quality can affect the cause of emmetropization towards myopia
Optimized nutrition can be expected to help to reduce the magnitude of the emmetropization factor.

As a summary for section 3 the main problem for **serious progressive and pathologic myopia** (not for the low grade school myopia) can be seen in:

an overreacting immune system

an overreacting image-feedback system

an abundance of highly reactive oxidizing radicals

an insufficient antioxidant system

connective tissue degrading processes

a lack of nutrients, which are needed for the synthesis of connective tissue.

The difference between not very problematic, stable myopia and progressive myopia can be explained as shown in Figure 17.

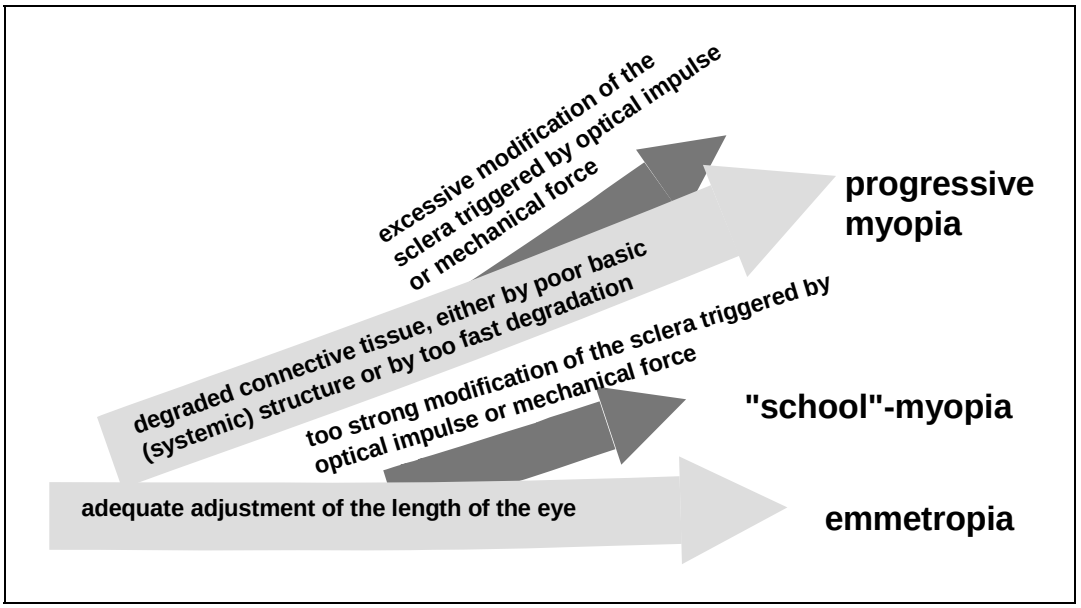
excessive modification of the sclera triggered by optical impulse or mechanical force
degraded connective tissue, either by poor basic (systemic) structure or by too fast degradation
progressive myopia
too strong modification of the sclera triggered by optical impulse or mechanical force
"school"-myopia
adequate adjustment of the length of the eye
emmetropia

Figure 17 The different paths to "school"-myopia and progressive myopia

The means for prevention of myopia and prevention of progression of myopia can be roughly described as shown in Figure 18.

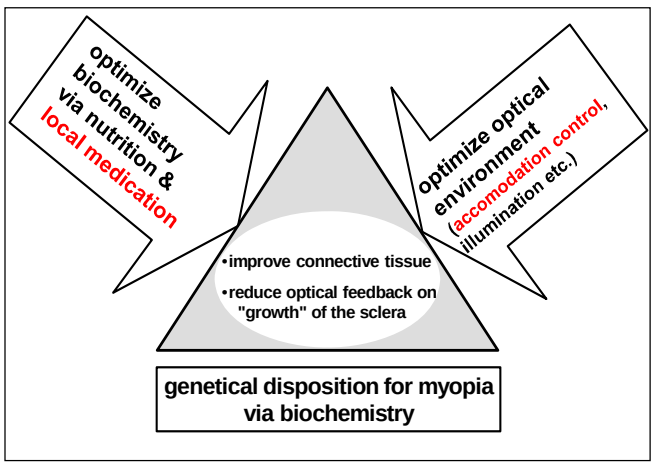
optimize biochemistry via nutrition & local medication
optimize optical environment (accomodation control, illumination etc.)
•improve connective tissue
•reduce optical feedback on "growth" of the sclera
genetical disposition for myopia via biochemistry

Figure 18
The means for the prevention of the progression of myopia

Optimizing the optical environment is important for **everybody**. In addition, optimizing biochemistry via nutrition is extremely important when fighting **progressive, more pathological** myopia.

All these advices are especially important for children, but they are as well important for adults of all ages.

3.31 For Further Reading –Extensive Compilations

The International Myopia Institute (IMI) has published in October 2018 a series of White Papers, which were written by numerous leading scientists and which are summarizing in detail the state of the research about Myopia in several sections[1089]:

IMI – Clinical Management Guidelines Report

IMI – Clinical Myopia Control Trials and Instrumentation Report

IMI – Defining and Classifying Myopia: A Proposed Set of Standards for Clinical and Epidemiologic Studies

IMI – Myopia Genetics Report

IMI – Industry Guidelines and Ethical Considerations for Myopia Control Report

IMI – Interventions for Controlling Myopia Onset and Progression Report

IMI – Report on Experimental Models of Emmetropization and Myopia

These White Papers can be downloaded free of charge.

Brennan et al. published[1090] an extensive review of various means of myopia control "Efficacy in Myopia Control".

Note:
In these papers it is considered to be doubtless fact, that myopia has its origin in signals to the retina only, and therefore mechanical reasons are ignored.
This is, however, in contrast to research results mentioned in section 3.2.1.2, where the elongation of the eyeball already by short-term accommodation is described.

Recommendations for preventing or inhibiting the progression of myopia	
Recommendations from the **optical side** **(mainly to compensate the negative effects of excessive near work)**	**Potential risks**
For near work keep a reasonably large distance to your book / paper / computer screen, even when wearing plus additions. ***Note:*** *Reading in bed leads mostly to a distance, which is too near.* **Do not use glasses or contact lenses, which are stronger than necessary,** i.e. avoid any overcorrection**.** You might use "main glasses / contact lenses" which are slightly under-correcting and you use additional glasses for perfect distant vision. **If you are not myopic yet, better use plus glasses for extensive near work.** **If you are already myopic, use bifocal or progressive glasses or bifocal contact lenses, or use plus glasses additionally to your contact lenses for extensive near work.** **Interrupt your near work** every 30 minutes by focusing on distant objects and **relax your eyes especially in the evening before going to sleep**. **Wearing plus glasses for a short time every day may be of some help.** **Cold-color light** should be preferred to warm-color light. **Do not read and don't do near work at bad light, 500 Lux** are the minimum, but substantially higher levels are recommended depending on the visual task (e.g., for detailed drawing work 1,500 to 2,000 lux). Some **exercising of the accommodation** by alternating focusing near and far objects can be helpful (but don't expect miracles from classes which are offered about this issue). **Take care to have enough sleep at the proper time** and in darkness**. Do not keep a light switched on in the kid's room at night** (there is a controversy in the literature about night lights, but better be on the safe side). Perform regular **physical exercises, preferably outdoors,** and use sunglasses in **rather bright sunlight only**	No risk, but avoid a permanent and substantial undercorrection without the consultation of an ophthalmologist, as an inappropriate undercorrection or inappropriate bifocals may create, e.g., a deprivation effect[202].
Discuss with your ophthalmologist the application of **atropine drops**. Consider **rigid gas permeable contact lenses** (RGP). Soft contact lenses were not reported to show a positive effect, but soft bifocal contact lenses showed a positive effect, too. Consider **orthokeratology.**	None if properly and professionally applied.

Table 10 Optical recommendations for preventing myopia or inhibiting the progression of myopia

Recommendations for preventing, or inhibiting the progression of myopia	
Recommendations from the **behavioral and the nutritional side (mainly to reduce an elevated personal emmetropization factor)**	**Potential risks**
Reduce negative mental **stress**, possibly by appropriate **physical and mental exercises, and playing**. **Physical exercises** can as well have a positive impact on the blood circulation in the eye, and promote NO metabolism. Especially **Outdoor activities** were shown to be very effective to prevent myopia (preferably 2 to 3 hours a day).	Avoiding stress can prevent a potential risk for your professional career.
Keep a **healthy and balanced diet**, which is **low in sugar and low in refined carbohydrates** (incl. white wheat), **low in sodium**, low in fat except omega-3 (fish) oil, and have **plenty of (if possible unprocessed) vegetables and fruits**. There are many books for a healthy diet on the market, with tables showing the contents in specific nutrients[1091].	None
If the progression of your myopia is worrying you, **additional supplements** of **multiple vitamins** (especially the vitamins **E, B2, B6, folic acid**), **minerals** (especially of **calcium, selenium, copper and zinc**) and especially also of **flavonoids** are recommended. Only for the **B vitamins** doses substantially higher than the recommended daily doses may be helpful, (for flavonoids no recommended doses are available). Especially if your ancestors came from regions with plenty of sun, you may easily have an individual lack of **vitamin D. A 25(OH)D blood test is highly recommended.** In general, our ancestors spent by far more time outdoors, which gave them plenty of vitamin D. Therefore it is recommended to have your Vitamin D status checked and to take supplements in case the level is not optimal.	Do not take higher doses of **vitamin A** than the recommended daily allowance for it and keep the appropriate balance between **copper and zinc**, and **calcium and magnesium.**

Table 11 Behavioral and nutritional recommendations for preventing myopia or inhibiting the progression of myopia

4 Additional Information

This section contains numerous hopefully helpful hints and explanations dealing with the myopia issue. These hints and explanations cover the correction of myopia by glasses, contact lenses or surgical operation, as well as the dosage of dietary supplements.

4.1 Optical Correction

4.1.1 Glasses

Often the customer is not aware of the big variety in the quality of optical glasses. This section should help to ask the optician the right questions when ordering new glasses (even if you are wearing contact lenses you need spare glasses).

4.1.2 The Material of the Glass

The refractive index of the lens material determines the thickness of the lens: The higher the index, the thinner the lens (which is important for higher degrees of myopia). For mineral ("real") glasses the index is between 1.5 and 1.9, for organic ("plastic") glasses the index is between 1.5 and 1.7. Generally the rule is, the higher the refractive index, the higher the price of the glasses. Therefore highly myopic people who generally need thick glasses have to spend more money to get thinner (better looking) glasses.

Often not only the thickness of the lens is important, but also the weight: Organic lenses are lighter than mineral lenses, and for the mineral lenses the rule is, the higher the refractive index, the higher the specific weight.

A few numbers for comparison:

The Edge **thickness** for a lens with 65 mm diameter, a power of D = - 10.00 and a refractive index 1.5 is 13.3 mm, and for a refractive index 1.9 the edge thickness is 7.4 mm.

The **weight** of a lens with 65 mm diameter, a power of D = - 10.00 and a refractive index 1.5, made of a mineral glass is 56 gram, whereas the weight for an organic glass is only 33 gram.

A few typical numbers for the specific weight are shown in Table 12:

Material	Refractive index	Specific weight in gram/cm^3
Organic glass	1.5	1.32
	1.6	1.34
Mineral glass	1.5	2.55
	1.6	2.67
	1.7	3.19
	1.8	3.62
	1.9	4.02

Table 12 Data of some materials used for glasses

Another parameter of the lens material is the dispersion, i.e. the difference of the refractive index for various color components, which can result in disturbing color effects on the edge of the lens. Generally, the higher the refractive index, the higher the problem of dispersion.

Additionally, the glass should have a high absorption of UV light.

4.1.3 The Coating of the Glass

Without a coating, there would be very disturbing reflections on the surface of the glass, for example making the eyes "invisible" to other people, and which create reflections of light which are very disturbing during night driving.

For organic glasses there is another reason for coating: The relatively soft surface has to be protected from getting scratched too easily.

Overall, up to ten layers have to be brought to the lens, and significant differences in quality (and price) can be found for lenses from different manufacturers, and for different product lines of the same manufacturer.

4.2 Contact Lenses

(General sources[1092, 1093, 1094, 976])

Already in 1999 it was reported that worldwide about 80 million people wore contact lenses, with about 33 million people in the USA at this time.

A person who is switching from glasses to contact lenses experiences a magnification of the image on the retina. Table 13 compares the image size on the retina for people with glasses and for people with contact lenses[1095] (image size for contact lenses are rather similar to emmetropic people).

Myopia in D	Increase of image size by contact lenses compared to glasses
- 5.00	7 %
- 7.50	10 %
- 10.00	14 %
- 15.00	23 %

Table 13 The image size when using contact lenses compared to glasses

As the **accuracy of vision** is, among others, determined by the "granularity" of the retina (see section 1.11) for higher grades of myopia a smaller image results in poorer vision.

Additionally it was found that contact lenses improved the **contrast sensitivity** for high myopes (more than - 6.25D)[405].

Contact lenses have some general advantages, e.g., no dimming by condensed water or rain. Features greatly depend on the type of lens.

4.2.1 Basic Types of Lenses – Soft Lenses versus Hard Lenses

The different types of contact lenses are:

Hard lenses (this type of contact lenses was developed first):

- Rigid gas permeable (**RGP**) lenses, which allow substantial oxygen supply for the cornea through the lens.
- Lenses with low or no transmission of oxygen, type **PMMA or CAB** (obsolete, should not be used any more).

Soft lenses, which are containing between 35% and 85% water, and which are soft and flexible when they are wet:

- **Conventional soft lenses**, with no specific time schedule for replacement (unplanned replacement).

- **Planned-replacement lenses**, which are regularly replaced typically every month, or quarterly, or every 1-2 weeks (depending on the instructions of the practitioner and the lens manufacturer).
- **Disposable lenses**, which are used once and then discarded (no maintenance for cleaning).

For hard lenses the shape remains the same after being put on to the cornea. For **soft lenses the shape is modified**, because the lens adjusts to a great extent to the shape of the cornea. This can be expected to result in spherical aberrations, which decrease the image quality.

Typical features of the individual types of lenses are shown in Table 14 and Table 15:

Hard RGP contact lenses	
Advantage	**Disadvantage**
Suitable for stabilization of myopia? Can correct some astigmatism without toric lens design. Excellent optical quality and quality of the surface. Little absorption of chemicals. Less frequently serious eye infections than with soft lenses. Fewer deposits on the lens. Can be polished if scratched; edges and power can be manually optimized. Additional oxygen supply by exchange of tears during blinking. Average lifetime of the lens several years Easier maintenance. Lenses for very high grades of myopia available. Normally all lenses with an accuracy of 0.25 D available.	Needs highly qualified professional for proper fitting (especially difficult to fit when the lid tension is high). Longer time for getting used to the lens (up to 3 weeks). Occasionally less comfortable (depends largely on quality of fitting). Dust may be more disturbing than with soft lenses (because of smaller size). Loss of the lens is more likely than with soft lenses (because of smaller size). Not suitable in cases of highly fragile epithelium of the cornea. Not so suitable if worn occasionally only. Few types of lens have a scratch sensitive coating.

Table 14 Features of hard (RGP) contact lenses

	Soft contact lenses	
	Advantage	**Disadvantage**
General and conventional type (i.e. no specific time schedule for replacement)	Better compatibility, often immediately comfortable. Easier to fit (but maybe only because a miss-fitting is not realized in the short term). Less sensitivity to dust. Rarely any dislocation or loss of the lens, e.g. during sport activities. Suitable for frequent changes between contact lenses and glasses.	Easy absorption of chemicals, e.g. from cleaning. Badly fitted lenses stay unnoticed for a longer period, which may create long-term damages. Higher rate of complications were reported (maybe caused partly by unprofessional fitting). Less crisp vision than with hard lens. Average lifetime of the lens less than 1 year. Gets damaged easily. No oxygen supply by exchange of tears during blinking. More accumulation of surface deposits. More complicated/expensive maintenance. Frequently not available for high grades of myopia, and sometimes with an accuracy of 0.50 D only. Difficult to verify lens parameters. Correction of astigmatism requires toric lens.
Planned replacement	Less lens degradation. Easy to have spare lenses.	Less variety of lens parameters available.
Disposable	No cleaning of lenses. Less lens degradation. Easy to have spare lenses.	Still less variety of lens parameters available. Potential edge and surface problems depending on manufacturing process.

Table 15 Features of soft contact lenses

It was estimated that the probability for microbial keratitis (disease of the cornea) is about 3-fold for daily-wear soft lenses, and about 20 fold for extended wear soft lenses, compared with daily-wear hard RGP lenses[1096]. Other authors claim that this rate is mainly a matter of proper fitting and mainte-

nance[976]. The time for recovery was reported to be substantially shorter for incidents with hard RGP lenses than for soft lenses[1097]. Additionally, it was reported that the corneas of RGP wearers contained less bacteria[1098]. Therefore, it was reported that most of the people could not wear their soft lenses any more after 15 years[1064] (see section 4.2.3 informs about potential complications).

Those who wear the lenses overnight have a risk of eye infection 10 to 15 times that of users who insert and remove the lenses daily[1099].

Lenses for continuous wear – like for 30 nights and days – with very high oxygen transmissibility are available as RGP lenses and as soft lenses. As with normal lenses, it was found that RGP lenses for continuous wear showed fewer adverse events[1100], especially fewer bacterial infections[1101].

People, who use lenses for continuous wear should do so under the strict control of an experienced practitioner, who follows established guidelines[1102].

Therefore the tradeoff appears to be to choose between a

More healthy, but maybe a little bit less comfortable lens – the hard RGP lens, and a

More comfortable, but maybe somewhat less healthy lens – the soft lens.

A survey among members of the Contact Lens Section of the American Academy of Optometry showed that among these professionals RGP lenses were rated superior to soft lenses in most respects, especially quality of vision, eye health, ease of care/handling, and deposit resistance[1103].

Interestingly, a report from USA says that higher education makes hard lenses more popular than lower education, where wearers of hard lenses had a higher average income, and among soft lenses people with lower education favor disposable lenses[1104].

There are significant regional differences as well: In the USA only 12% of new fits are done with RGP lenses, in Japan more than 50% of new fits are using RGP lenses[1105].

There are by far more soft lenses sold than hard lenses – which creates, by the way, more revenues for the industry, and allows individual opticians to enter the business, who are hardly qualified for the more demanding fitting of hard lenses.

The new lenses made of silicon hydrogel can eliminate the disadvantages of the low oxygen transmissibility of the traditional soft lenses. Problems with microbial infections can still exist in a few cases, however, especially with extended wear[1106].

The fitting process of these silicon hydrogel lenses appears to be more demanding than the fitting of conventional soft lenses, as Holden stated[1107]: "We're back in the fitting business with silicone hy-

drogels. Manufacturers should pay attention to the edge shape of these stiffer lenses, and practitioners should make sure they've selected the appropriate diameter and base curve." It looks like, however, that these lenses are hardly available with a broad span of variable parameters so far. Therefore, lesions of the cornea due to not-optimal fitting might develop – it depends highly on the skill of the optometrist.

There is a variety of silicon hydrogel materials[1108], and the water content can range from 0% to 60%[1109]. The lenses with high water content can be expected to be more similar to soft lenses, and the lenses with low water content can be expected to be more similar to RGP lenses.

4.2.2 How about Lenses for Permanent Wear?

Generally, it is differentiated between:

Daily wear, for usage up to about 18 hours, and

Extended wear, for overnight use, e.g. for several days, and

Continuous wear for up to 30 days and nights.

It was claimed that lenses made of silicone hydrogel are already completely safe for 30-day extended wear[1110, 1111]. There are, however, still reports about increased amounts of deposits on the lens and dehydration of the lens[1112], and an increased amount of metaplasia (abnormal cell structures) of the cornea[1113]. Morgan stated[1114]: "There is a significantly higher incidence of SK [severe keratitis, an inflammation of the cornea] in wearers who sleep in contact lenses compared with those who only use lenses during the waking hours. Those who choose to sleep in lenses should be advised to wear silicone hydrogel lenses, which carry a five times decreased risk of SK for extended wear compared with hydrogel lenses." Morgan concluded additionally[1115]: "Practitioners should anticipate fewer adverse events with rigid versus soft lenses prescribed for continuous wear. Experienced wearers are less likely to discontinue compared with neophytes."

Comparing silicone hydrogel lenses with very high oxygen transmissibility and daily wear lenses with low oxygen transmissibility it was found by Bergenske[1116]: "During the 3 years, lotrafilcon A lens wearers who wore their lenses continuously for up to 30 nights showed stable, long-term improvements in many signs of corneal health and symptoms along with less myopic progression versus daily wearers of low-Dk/t hydrogel lenses. Many biomicroscopy signs and symptoms worsened among neophytes wearing daily-wear low-Dk/t hydrogel lenses. The use of lotrafilcon A lenses may minimize many ocular changes from soft contact lens wear."

4.2.3 Potential Complications

When getting contact lenses fitted, and for daily care extra cleanliness and accuracy are necessary. The following list of a few of the numerous potential incidents should not prevent anybody from wearing contact lenses. It should be, however, a good reason to be sensitive, to handle the maintenance with great care and to see the ophthalmologist (or optometrist) without any delay, if something unusual is noticed.

The practitioner can **check the status of the cornea** by the application of fluorescein to the eye. Damages to the cornea appear as stains. From the location of the stains conclusions about the fitting or corneal damages (e.g. caused by dust particles) can be drawn.

Frequent **deposits on the lens** (or even a blurred lens) are an indication that something is wrong, either with the mechanical properties of the lens, with some chemical toxication of the lens, or with too long wearing. A visit to your practitioner is strongly recommended.

If the lens cannot be removed as usual, there might be a **tight lens syndrome**. Do not apply force, better apply some saline solution or wetting drops, or see your practitioner.

The lack of oxygen generally (e.g. at night or when using lenses with low oxygen transmissibility) causes a swelling of the cornea, an **edema**. Depending on the transmission of oxygen by the lens, edemas occur to various degrees even when wearing at daytime only. It is not just a mechanical swelling, but a shift in various biochemical processes.

There are bacteria, which are growing best when exposed to an environment with low content of oxygen. Additionally, these edemas make it easier for bacteria to invade. These facts result in **extra risks when wearing contact lenses over night**[1064] (or lenses with low transmissibility in general).

Extended lack of oxygen in the cornea can lead to the building of new blood vessels from the conjunctiva to the cornea, called **vascularization**.

A chronic inflammation of the conjunctiva may become **giant papillary conjunctivitis (GPC)**, with papillae developing on the conjunctiva up to a size of 2 mm.

Small wounds in the cornea can become an **ulceration** of the cornea.

More generally, **bacterial and fungal infections** caused by dirty lenses, as well **as residual toxic or allergic traces of agents for lens care** can cause serious damage to the eye, especially if they are taken care of rather late.

4.2.4 Parameters of the Material for Contact Lenses

So far, the selection of the ideal material for contact lenses has often been a compromise, e.g. best oxygen transmission may be accompanied by limited wettability, or increased fragility. The art of fitting the lenses consists in selecting the best lens type for the specific needs of the individual customer. Individual characteristics of a patient are e.g. duration of wearing every day, quantity and quality of tears (there may be above average lipids), tension and geometry of the lids, quality of the cornea, sensitivity of the cornea, and working environment (like dust).

For hard RGP lenses, there is a rather small number of manufacturers of the basic material for the lenses, and they often leave the cutting of the final lens to a large number of final distributors. All the lenses are cut from bulk material.

For soft lenses, the complete manufacturing of the lenses is in one hand, and a few large companies are covering almost the whole market. The lenses are either cut from bulk material, molded, or spin cast.

4.2.4.1 Oxygen Transmission

Limited oxygen supply for the cornea (hypoxia) is a central problem for all contact lenses. These hypoxic effects include corneal swelling, endothelial blebs, epithelial desquamation, change of epithelium cell structure, and biochemical changes like the release of intracellular enzymes (like lactate dehydrogenase) into the tear fluid. The swelling of the cornea occurs at night even without any lens, because of the coverage by the lid. Clearly, these tiny damages are making the cornea more vulnerable to bacterial and fungal infections.

Due to this hypoxia at night it is recommended, to wait in the morning some 15 minutes before putting the lenses in to the eye to allow the cornea to recover from the lack of oxygen.

The units, in which the transmissibility of oxygen is measured is called **Dk**, with the following dimension:

$$10^{-11} \cdot \frac{\mathrm{ml\,O_2 \cdot cm^2}}{\mathrm{ml \cdot sec \cdot mm\,Hg}}$$

The data for Dk can be obtained by two different ways for measuring, one is called "gas to gas", the other one is called "ISO/FATT", sometimes called polarographic method.

Typical values for ISO/FATT-Dk are between about 10 and 200, where the gas to gas numbers are between 40% and 100% higher than the ISO/FATT numbers. Mostly the data are given in ISO/FATT units. Clearly, the higher the number, the better the oxygen transmission.

It appears that for the lenses currently on the market the average Dk/L numbers of hard RGP lenses are somewhat higher than that of the soft lenses. The leading manufacturers of soft lenses, however, have a very broad portfolio of lenses with very different Dk/L numbers – a good reason to ask your practitioner carefully what lenses you are supposed to get.

As Dk describes the properties of the material only, it does not take into account the thickness of the lens. Therefore a number **Dk/L** is defined, where L relates to the thickness of the lens. The dimension of Dk/L is:

$$10^{-9} \cdot \frac{ml O_2 \cdot cm}{ml \cdot sec \cdot mmHg}$$

The thickness of the lenses in the center is between about 0.08 mm and 0.15 mm for hard RGP lenses and between about 0.04 mm and 0.15 for soft lenses (in reality the fact that the thickness varies over the surface of the lens, and is smallest in the center, has to be considered for the Dk/L calculation as well).

Table 16 shows a summary of a few reports about the impact of various Dk/L numbers, not taking into account additional oxygen supply by the exchange of tears for hard lenses:

Dk/L	Impact on the cornea
23	Required for minimum oxygen supply to the basal epithelium of the cornea of the open eye[1117].
24	Required for daily wear without cornea swelling[1118].
35	Required for minimum oxygen supply for the whole thickness of the cornea of the open eye[1117].
87	Required for wearing at night without any additional swelling[1118].
89	Required for minimum oxygen supply to the basal epithelium of the cornea of the closed eye[1117].
125	Required for minimum oxygen supply for the whole thickness of the cornea of the closed eye[1117]. No increase in epithelial lactate levels[1119]. Still no normal oxygen supply[1120]. Decreased thickness of the cornea after 3 months, but no change after 1 month of extended wear[1121].

Table 16 The impact of the oxygen transmission Dk/L of contact lenses

As a summary, and considering the state of the art of currently available lenses, **Dk/L numbers should be over 25 for daily wear in any case**, but lenses with numbers **over 35** are widely available and are **clearly more recommended.**

Another way to measure the oxygen supply to the cornea is the **EOP** (equivalent oxygen percentage) number, which indicates the percentage of oxygen directly at the cornea. At sea level and without a lens EOP equals about 21%.

For **extended wear** a minimum EOP of about 18% (corresponds to about Dk/L 85) is recommended, for **daily wear** a minimum EOP of about 10% (corresponds to about Dk/L 25) is recommended.

During sleeping, the EOP is only 7.7%, which explains the swelling of the cornea at night. As it takes some time for the eye to return to a normal oxygen status after sleeping, it is advised to wait some time (about 15 minutes) before using the contact lenses.

The exchange of tears by blinking when wearing hard lenses can contribute an additional EOP of about 3% to 4% (for the old hard lenses made of PMMA material this was the only one way of oxygen supply).

The higher the Dk of a lens, the shorter is generally the life expectancy of the lens[1122], and for soft lenses there is a general relation: The higher the water content, the higher the oxygen transmission.

As result of a study it was concluded: "High-Dk silicone hydrogel lenses can be worn for up to 3 years with virtual elimination of the hypoxic consequences observed with low-Dk lenses made from conventional lens materials."[1123]

There is evidence that the lower the Dk/L of the lens is, the larger the thinning of the epithelium of the cornea is[1124]. This thinning of the epithelium was still observed with lenses with Dk=140 (continuous wear), and the thinning was still evident after 3 months with no contact lenses[1125]. This thinning is sometimes primarily attributed to a lack of oxygen, sometimes primarily to the mechanical pressure which is applied by the lens.

4.2.4.2 Wettability and Resistance against Deposits

A lens with excellent oxygen transmission, but poor wettability and poor resistance against deposits is not acceptable.

There is a scale for the **wetting capability**, the wetting angle. It can be measured by two procedures (with different resulting numbers):

The "**captive bubble**" method measures the angle between the edge of an air bubble and the lens surface, with the lens immersed in water or saline.

The "**sessile drop**" method measures the angle between the edge on a drop of water and the lens surface.

For both numbers the rule is: The lower the angle, the better the wettability.

There exists no measurement procedure for the **resistance against deposits**, which consist of tear mucin and protein (and bacteria). Whether there is a problem with deposits, depends heavily on the consistency of the tears of the individual person. If there are irritations of the eye due to a lack of oxygen or mechanical stress of the lens on the cornea, deposits will increase substantially.

Different lens types can have significantly different resistance against deposits, and it is up to the practitioner to select the proper material – and it is up to the user to be very careful about daily cleaning. Mainly the deposit problem is the reason for the recommendation to change regularly to new lenses – especially for lenses with a very high Dk.

Sometimes the wetting capability of brand new RGP lenses is caused by deposits from the manufacturing process. Professionals have specific solvents to remove these deposits[1126].

4.2.4.3 Hardness and Stability

The hardness of lens materials is only specified for hard lenses. It is measured in Rockwell (a sharp sample is pressed onto the material, and the remaining depth of the damage is measured) and in Shore (a hard ball is dropped onto the material, and the height to which the sample is bouncing back is measured). The Rockwell numbers give more of an indication for the resistance against scratches; the Shore numbers describe more the elasticity. The higher the oxygen transmission of the lens is, the softer the material in many cases.

A soft lens does may not be more comfortable, as blinking may cause a deformation of the lens and a transient edge lifting, which interacts with the upper eyelid[1127].

A hard, rather inflexible lens will be more suitable for masking astigmatism of the cornea than a flexible lens, which will just take the shape of the cornea.

Warping of the lens may be an issue for the longer term: It is the capability of the lens to keep exactly its shape, and not to become distorted. Very thin, hard lenses are more likely at risk for warping or even for breaking.

Sometimes the shape of the contact lens is changing in a way that the fitting of the lens becomes more flat (larger Base Curve Radius, see section 4.2.5). This "extra lens which consists of tears" under the contact lens adds to the power of the contact lens, which results in an overcorrection with all the negative influence on a progression of myopia. There are two ways to avoid this problem: Get contact lenses with a high degree of stability (your optometrist might consult you), and/or have the geometry of your lenses checked regularly.

4.2.4.4 Specific Weight and Refractive Index

These two parameters are sometimes expected to be important - mainly for contact lenses of higher grades of Diopter because of a higher volume of the optical part: A heavier lens (i.e. of higher specific weight and lower refractive index) might have more a tendency to move downward, i.e. centration is more likely to become a problem.

Detailed analysis and experiments, however, have shown that "the lens **mass is not a significant predictor of lens dynamics**." More important is the **center of gravity** of the lens. Carney et al. stated[1128] that "... lenses with a center of gravity location further behind the lens vertex show better stability." The center of gravity is shifted into this direction by an increasing diameter, decreasing lens thickness (and increasing negative power and increasing lens curvature, but these two are determined already for other reasons).

Anyway, a lower weight of the lens can be achieved by manufacturing it from a material with lower specific weight, with minimal center thickness (depending on the specific material), or by a specific lens cut called lenticulation[1129].

4.2.4.5 UV Blocking

Most lenses are coming with a substantial UV blocking capability; this should never be considered, however, as a substitute for wearing sunglasses.

4.2.4.6 Color / Tint of the Lens

There are tints, which are used for cosmetic reasons, i.e. to enhance or even to change the color of the iris of the eye, and there are more pale tints, which are applied to make the lens more visible to ease the handling of the lenses. This pale tint, e.g., can make it easier to find a lens, which dropped down.

4.2.5 Parameters of the Geometry of Contact Lenses

In principle, hard and soft lenses are described by the same set of parameters. For hard lenses, however, these parameters are by far more important, and the lenses are available with by far more detailed numbers of these parameters. Because of this large variety of hard lenses, the final lenses for an individual customer are custom made, and the practitioner is working with a set of trial lenses only, which is normally do not match with the final required refractive power. Soft lenses, however, are generally "ready to go" because of their rather limited spread of parameters – sometimes the refractive power is the only parameter.

The geometrical parameters are:

Diameter of the Lens (TD, Total Diameter)

Typical diameters of hard RGP lenses are between 9.00 mm and 10.50 mm; the selected size depends e.g. on the diameter of the iris, and the position of the upper eyelid, i.e. whether the upper edge of the lens should stay covered by the lid ("lid attachment") or not ("interpalpebral").

It was noted[1130], "High powers require larger diameters for lens stability because the heavier lens may sink down if it is not caught by the eyelid."

Generally, lens diameters above 9.5 mm were found to be more comfortable[1131].

Typical diameters of soft lenses are between 13 mm and 15 mm.

Astonishingly, a report found that oxygen uptake increased with increasing diameter of hard lenses (and their typical diameter)[1132]. A large diameter of a hard lens may create, however, problems for fitting, if no aspheric design is used (see "Aspheric Design", below).

Base Curve Radius (BCR, or Back Optic Zone Radius BOZR)

This very important number determines the fit of the lens on the cornea, and it is for hard RGP lenses between 6.50 mm and 9.00 mm; this radius is available with a granularity of 0.1 mm or better of 0.05 mm. A lens manufacturer, which delivers 0.05 mm granularity, should be preferred, because this allows a more accurate fitting of the lens – especially if the selected lens material is rather rigid.

For soft lenses, the exact fit to the cornea is by far less important, because due to their flexibility they can adjust to the radius of the cornea. Very often soft lenses are coming with one radius of about 8.6 mm only; sometimes there is a choice between numbers like 8.4 mm, 8.7 mm, and 9.00 mm.

Sometimes the curvature of the cornea is not described by its radius in mm, but by its corresponding Diopter number. The formula for conversion is:

$$D = \frac{337.5}{R}$$

where D is the Base Curve Radius in Diopter, and R is the Base Curve Radius in mm.

Because of the lens built by the tear-liquid between cornea and contact lens, a transition to a flatter lens than the previous lens results in a lens with less Diopter (weaker power), whereas a transition to a steeper lens results in a lens with stronger power. 0.05 mm change in BCR corresponds to about 0.25 Diopter.

Aspheric Design, Secondary Curve Radius (or Back Peripheral Radius BPR)

When contact lenses were first introduced, both sides of the lens were spherical. However, this matches the shape of the cornea only for very small lenses. In reality the cross section of the cornea looks more like an ellipsoid or a paraboloid. Carney et al. stated[412]: "A tendency for the cornea to flatten less rapidly in the periphery with increasing myopia was shown, however."

Consequently, there were other back surfaces developed, created by one of these methods:

- An aspherical outer curve is joined to the inner spherical curve, i.e. the lens becomes progressively flatter towards the edge. As the cornea itself is aspheric, a closer fit to the cornea can be achieved.
- Mathematically, the aspherical part of the lens follows the shape of a conic section, where a parameter e describes the eccentricity of the selected conic section: for spheres e equals zero, for ellipsoids e is between 0 and less than 1, for paraboloids e equals 1. Typically, the cornea corresponds with a value for e between 0.4 and 0.6.
- A disadvantage is that it is more difficult to verify the parameters of a lens, or to compare lenses from different manufacturers – and they are often more expensive.
- Various spherical curves are joined onto each other, with the curves with the larger radius towards the edge of the lens. This lens design is normally used for very special cases and custom design only.

Most common (and cheaper) lenses are, however, still simple spherical designs.

Shape of the Edge, Edge Lift

The shape of the edge of the lens, where the outer surface is meeting the inner surface, is primarily important for hard lenses only. This shape is mathematically hard to describe and usually at least partly hand made at the manufacturer's laboratory. Nevertheless, the specific shape of the edge is very important to feel comfortable with the lens, as well as for an efficient tear exchange.

A larger axial edge lift (up to 0.3 mm) was found to be less comfortable than a lower axial edge lift (around 0.1 mm), which gave a better-centered lens as well[1133].

More experienced practitioners are able to modify the edge of a lens according to the specific needs of a customer.

Center Thickness

The thickness of the lenses in the center is between about 0.08 mm and 0.15 mm for hard lenses and between about 0.04 mm and 0.15 for soft lenses. The thickness of the lens has not only an impact on the oxygen transmission, but also on the flexibility of the lens: To avoid in certain cases a warping of the hard lens, a lens with increased thickness is provided.

Back Optic Zone Diameter (BOZD or OZ)

The back optic zone is the area, which has the "right" optic without any disturbing optical effect of the aspheric design, or a secondary curve. This diameter should be not too small for good vision.

The Power of the Contact Lenses

The numbers for the refraction of the glasses and for the refraction of the contact lenses are different, especially for higher grades of myopia. The formula is:

$$D_{lens} = \frac{D_{glasses}}{1 - d \cdot D_{glasses}}$$

where d is the distance between the cornea and the glasses in m (sometimes called vertex distance).

An example:
With $D_{glasses}$ = - 10.00, and d = 16 mm the power of the contact lenses D_{lens} = - 8.62

By the way, this effect can also be visible when the refraction is measured für spectacle wearers and when the frame for testing has a different vertex distance than the finals spectacle glasses, possibly resulting in over-correction.

Additionally, the refractive power of the tear-liquid filled gap between the cornea and the contact lens has to be considered. For a flat fitted lens (i.e. with a larger BOZR), this gap acts as an additional minus lens. The power of this additional lens can be between zero D for a lens fitted exactly to the cornea and - 1.00 D for rather flat fitted lenses and has to be considered when determining the power of the final lens:

A change of 0.05 mm in the BCR (Base Curve Radius), or BOZR (Back Optic Zone Radius) results in a change of 0.25 D of the lens system, i.e. a lens that is 0.05 mm flatter has in effect - 0.25 D more refractive power.

Toric Components

To compensate astigmatism a toric component can be added to the lens, similarly like for conventional glasses.

Special cuts of contact lenses, which take care of presbyopia are discussed in section 4.2.12.

4.2.6 Surface and Edge Finishing

A few big companies make the basic material of the lenses, but numerous smaller vendors do the final manufacturing especially of the RGP lenses. Different materials are requiring different surface finishing processes, and different manufacturers of the lenses may achieve different qualities. This should be considered when switching to a new material or another optometrist who is buying from a different vendor.

Frequently the edges of RGP lenses are still finished manually. Consequently, this process depends on the skill of individual people and appropriate quality control.

It was reported that there is a quality problem for daily lenses, i.e. lenses, which are used only once [1134]: Due to this cost effective mass production about 2% of these lenses might be of reduced quality, e.g. have a higher surface roughness. In the worst case, this might lead to a permanent incompatibility of contact lenses.

4.2.7 The Fitting of Contact Lenses

A description of the fitting process is beyond the scope of this book, and there are very good sources about this issue available[1092]. Therefore just a few remarks:

There are several successful strategies of how to fit the best lens (especially for hard RGP lenses). Basis of each fitting process is a measurement of the topography of the eye, especially the various radii of the cornea, measured in different directions, and in the center as well as in the periphery.

A general differentiation is between a more flat fitting and a steeper fitting: Flat fitting means that the base curve radius (BCR / BOZR) is clearly larger than the radius of the cornea. This results in some edge clearance, which allows for enhanced exchange of tears and oxygen, and good mobility of the lens, but the lens may become more off-centered (which may have unwanted long-term effects on the shape of the cornea). Steep fitting means that the base curve radius closely matches the radius of the cornea. This results in a good central position, but if the lens is sitting too tight (i.e. too steep fitting) a "tight lens syndrome" may develop.

Fitting of hard lenses is more demanding than the fitting of soft lenses, but a bad fitting of a hard lens is noticed earlier, generally before some damage happens to the eye.

Special harm can be done by overly tight lenses, i.e. which don't move during blinking.

An irritation can be caused not only by a lens that was fitted too steep (most uncomfortable) or too flat, but also by the sliding of the upper lid over the edge of a rather small lens[1131]. A larger lens might help in these cases.

When changing from older, non-gas-permeable lenses (PMMA-type) to highly gas permeable lenses the fitting should be done either without any break in between, or with a break of several weeks[1092].

It is very helpful for the fitting practitioner, if the patient can describe the problem very clearly. Therefore it is helpful, to get the basic knowledge about the fitting process by yourself. This also enables you to ask the right questions (and to find out whether you are at the right practitioner).

Experience is a key issue to become an expert for fitting. Therefore, an ophthalmologist or an optometrist who is really focusing on contact lenses as the main job is most likely a better choice than somebody who is doing this task only occasionally.

4.2.8 The "Right" Power of Contact Lenses

In section 3.2.2.3.12 a summary of the various optical aspects which determine the "right" power of the glasses or contact lenses was given.

The thesis to avoid any avoidable accommodative load for the eye leads to these tradeoff-recommendations for contact lens wearers:

Have fully correcting contact lenses but wear additional plus glasses for extensive near work, or

Have under-correcting contact lenses but wear additional minus glasses for perfect vision for far (e.g. for driving).

Be aware that the power of contact lenses is lower than that of the respective glasses. The numbers for the refraction of the glasses and for the refraction of the contact lenses are different, especially for higher grades of myopia. The formula is:

$$D_{lens} = \frac{D_{glasses}}{1 - d \cdot D_{glasses}}$$

d is the distance between the cornea and the glasses in m (sometimes called vertex distance).

4.2.9 Determining the Refraction after Wearing Contact Lenses

When the refraction of contact lens wearers is determined – e.g. to fit spare glasses – it has to be considered:

Flat fitted lenses flatten the cornea (see section 3.26.2), herewith reducing the Diopter of myopia.

If lenses of low oxygen transmission (i.e. PMMA material) had been used, it takes 3 weeks until an accurate refraction could be determined. Rengstorff stated[1135]: "...myopia decreases over the first 3 days after stopping PMMA wear and then increases over several weeks until it stabi-

lizes." Therefore the transition to a material with high oxygen transmission can be accompanied by a wrong refraction and improper fitting

If the determination of the refraction, however, serves only the purpose of fitting spare glasses, these effects can be ignored, as these glasses are used in general immediately after wearing the contact lenses.

4.2.10 Maintenance of the Lenses

The maintenance procedure is different for hard RGP and soft lenses, but there are some general recommendations:

Generally, follow the routine recommended by the manufacturer of your lenses, and by your practitioner.

If you are not satisfied with your lenses, talk to your practitioner and ask him what other brands of lens care products, or what other procedures would be compatible with your lens type, and try them. There is a very big variety of lens care products, made by the manufacturer of the lens as well as products made by independent suppliers. There is always the possibility that you are sensitive against a preservative or tensides, which is used in a lens care agent.

4.2.10.1 Maintenance of Hard RGP Lenses

Essential for the maintenance of hard RGP lenses is the fact that they contain less than 1% of water, i.e. absorption of agents into the lens material is by far less a problem than for soft lenses. The steps of treatment are (not considering the necessary rinsing between individual steps):

a) Cleaning after the use to remove surface deposits.

b) Disinfecting over night.

c) Wetting before inserting into the eye.

d) Occasional enzyme cleaning to remove proteins, if necessary.

The cleaning solution for step a) contains tensides and, depending on the brand, some abrasive particles (a few lens types do not like abrasive agents!)

Normally the steps b) and c) are performed with the same type of agent, but this might not be the best for you: There are solutions which are very effective for disinfecting[1136], but which can be somehow irritating for wetting, when they come in direct contact with the eye[1137, 1138], and vice versa[1139]. Therefore, it could be very helpful for you to use **different solutions for step b) and for step c),** even though most solutions are claimed to work for both b) and c.

There are also solutions on the market that combine the steps a), b) and c), but do not be astonished if this compromise does not satisfy you; anyway, it is good that these products exist for the emergency case, e.g. for traveling.

Generally, the solutions of the various brands have a different composition. Therefore, in case of a problem, **a switch of the brands can be very effective**. Sometimes there can be interference as well, i.e. a cleaner from a certain brand might be comfortable with a disinfecting/wetting solution from one brand but not with another brand.

Occasional enzyme cleaning is efficient, but if heavy deposits build up frequently there might be something wrong with the lens. Enzyme cleaners can be based on either animal- or plant-enzymes, maybe you are more sensitive to one of them (there is always a chance that traces are left on the surface).

Special care has to be taken when cleaning the lenses by hand to avoid **warping** them – therefore some practitioners are recommending to put the lens into the palm of the hand for cleaning, and not to rub it between the tips of two fingers.

A **change of the lens parameters is not necessarily visible to the patient**: the lens can become **flatter in fitting**, which means **stronger in power**. This gives no immediate cause for complaint to myopes. Nevertheless, the resulting **overcorrection** can increase the myopia further as outlined before. Resulting **advice**: insist that your practitioner checks the parameters of the lens at least annually, and favor a material, which is more stable.

4.2.10.2 Maintenance of Soft Lenses

Essential for the maintenance of soft lenses is the fact that they contain a very substantial amount of water (35% to 85%), i.e. absorption of agents into the lens material is a problem. The steps of treatment are (not considering the necessary rinsing between individual steps):

a) Cleaning after the use to remove surface deposits.

b) Disinfecting by the chemical method, or by hydrogen peroxide, or by heat, or by UV-light, or by microwave radiation (depending on the individual lens).

c) Disinfecting is especially important for soft lenses, as some types of fungi can grow within 20 hours through a soft lens; bacteria and virus, however, cannot get inside a undamaged soft lens.

d) Storing, and wetting before inserting into the eye.

e) Occasional enzyme cleaning to remove proteins, if necessary.

For soft lenses the variety of lens care systems, which often combine steps mentioned above, is substantially higher than for hard lenses. The requirements are more dependent on the individual lens type. There are also "all in one" solutions on the market, similarly as for hard lenses.

The fact that proper lens care is more difficult for soft lenses than for hard RGP lenses is one of the reasons for the trend towards disposable soft lenses.

In any case, the specified intervals for renewing the lens should not be ignored.

4.2.11 "I Cannot Wear Contact Lenses"

This conclusion "I cannot wear contact lenses" might be not generally valid, but based on

Specific lens care liquids for cleaning or storing or wetting which you cannot tolerate.

Advice: Try other lens care liquid with another added preservative.

A specific lens material which is not suitable for you (this might be influenced by the manufacturing process of the specific vendor). Silicone-hydrogel lenses, e.g., might create problems in case of elevated levels of lipids and proteins are in the tear liquid. Additionally, the specific combination lens material / lens care liquid can be the problem, if the lens material stores especially components of the liquid, against which the eye is sensitive.

Advice: Try other lens materials.

The geometry of your lenses.

Advice: Ask your optometrist to try a modified geometry. Soft contact lenses are often subscribed as "one geometry fits all"; this might be true for most of the people, but not for everybody. For soft contact lenses, different geometries are available as well as for RGP.

An irritation of the eyelid by the edge of the lens.

Advice: Ask your optometrist to try a modified geometry, especially a lens with a larger diameter might help.

"Dry eyes".

Advice: Frequently dry eyes are the main obstacles against the wearing of contact lenses. There can be several medical reasons which cause dry eyes, but there can be as well a more simple reason for dry eyes: **too less blinking**. It was stated[1140]: "The reason for this difficulty is that the frequency of blinking typically decreases during tasks that require concentration. As blink frequency decreases, there is more time for the tear film to evaporate.

A **simple exercise to improve the blinking** was given[1141]: "The exercise consists of a person placing his/her fingers lightly on the outside corners of both eyes. By blinking rapidly several

times, most people notice a pulling sensation as they blink. Blinking should be repeated slowly, ensuring that the eyelids close completely and that pulling sensations are no longer present. This may be achieved by concentrating on moving only the eyelid, during the blink. This exercise should be done several times each day and for one to two minutes each time the exercise is performed."

Additionally it was said[1142]: "Practitioners generally recommend soft **lenses made with a low water content because these lenses dehydrate less than high-water lenses do in a dry environment**."

With respect of the **influence of the diet on the tear function**, Caffery stated[1143]: "A review of the ocular literature suggests that sufficient dietary protein, vitamins A, B6 and C, potassium, and zinc may be necessary for normal tear function. Excesses of dietary fats, salt, cholesterol, alcohol, protein, and sucrose have been associated with or suggested as causes of tear dysfunction." Additionally, omega-3 fatty acids, which can be found, e.g. in fish oil and flaxseed were recommended for dry eyes[1144].

Note:
Overall, before you take more serious and final steps like surgery, ask your contact lens practitioner for different liquids, different materials, or, finally, go to a different practitioner – and take care of your diet and your viewing habits.

4.2.12 Presbyopia

For presbyopia, the contact lenses are required to replace the accommodation of the human lens, i.e. to offer focus as well for near objects as well as for distant objects, as with bifocal glasses (numerous other means to treat presbyopia were discussed in the literature[20]).

Wearers of glasses accommodate less and have lower convergence demands than emmetropes or wearers of contact lenses, i.e. myopic people wearing contact lenses should be affected by presbyopia more early than myopic people, which are wearing glasses[208].

There are some different concepts to handle presbyopia with contact lenses[1145]. Generally, there are two groups of systems, i.e. for alternating vision, where an image is produced either for distant view or near view, and simultaneous vision, where the evaluation of the different images is done in the brain. In any case, it will take a while until the patient is used to the new vision.

Specific contact lenses for presbyopia:

The optical zone of the lens is split into an upper section for distant focusing and a lower section for near focusing (alternating vision).

A problem is that the lens has to be kept in the right rotational and vertical position. The lens is difficult to fit, and is normally fitted flat.

The optical zone of the lens is split into a center section for distant focusing and a peripheral section for near focusing (simultaneous vision).

This lens is fitted more on the steeper side to have the lens properly centered. When the aperture of the iris is small, e.g. at bright light, near focusing may be a problem. As with all methods which are using simultaneous vision, the contrast of the images is reduced.

Notes:

- *The steep fitting, which is necessary to keep the movement of the lens at a minimum, might create a problem particularly for older people whose amount of tear liquid is frequently reduced.*
- *As with older age the ability to see in the dark and the contrast sensitivity fades generally, every optical device which increases these handicaps is problematic, especially when this device is worn permanently, i.e. when there is no way to improve the vision when needed, like for driving at night.*

Into the optical zone of the lens fine microscopic steps are inserted. These steps create via diffraction two focus points – one for distant vision and one for near vision (simultaneous vision).

An exactly centered position, and the aperture of the iris is not as important as in the method described on top. The reduction of the contrast, however, is similar.

In general, the visual performance of rigid gas permeable contact lenses was better than the performance of soft contact lenses.[1146]

Other methods to cope with presbyopia are:

Monovision: The lens of one eye is adjusted for distant vision; the lens of the other eye is adjusted for near vision.

This method is less expensive, and easier to fit than the previous methods. Good success rates have been reported for this method. For driving (especially night driving) the use of additional glasses, which compensate for the undercorrection of one eye, is recommended. Especially for reading additions that were not greater than 2.50 D the visual results were reported to be quite satisfying[1147].

Note:

In a professional discussion forum several optometrists expressed their opinion that monovision is clearly more comfortable to most patients than bifocals.

Good results were also reported for the combinations of monovision and LASIK[1148].

Permanent undercorrection to allow reading, use additional glasses for distant vision, e.g. for driving.

This method, however, can satisfy only in the early stages of presbyopia, when the resulting uncorrected distant vision is still acceptable for daily life (except driving), i.e. when it is around 1.00 D only. Moreover, this method can be expected to delay the total presbyopia, because the permanent accommodative effort keeps the own lens longer elastic.

Intraocular lenses which can accommodate.

In the trial status are intraocular lenses for people undergoing cataract surgery (i.e. whose lens was removed), which can accommodate via the ciliary muscle. While this sounds very promising for cataract patients, the risk of this operation for normal presbyopes without a cataract problem appears to be large, but this may change within a few years[1149].

Note:
Because of their shorter remaining life expectancy, long-term effects of surgery might be less important for patients with presbyopia than for young myopes.

4.2.13 Contact Lenses and Nutrition

Some nutritional components are especially supporting a healthy cornea, which is important when wearing contact lenses:

Vitamin A is generally necessary for the metabolism of mucous membranes, and a long-term nutritional deficiency causes severe damages of the cornea, which can lead to blindness.

Local, lesions of the cornea are often treated with eye drops containing **pantothenic acid (vitamin B5) or retinoic acid (vitamin A)**.

The mechanical stability of corneas was improved by treatment with **vitamin B2 (riboflavin) and UV irradiation**, introducing additional cross-links.

Therefore, and as vitamin B2 was shown to have a positive effect on the connective tissue in general it is advised to have sufficient vitamin B2 in the diet.

Note:
From this point of view, contact lenses, which are blocking UV light almost completely, are not of benefit in every respect.

The cornea needs manganese for the maintenance of its cell structure.

The stability of the tear film on the cornea is essential for comfortably wearing contact lenses. It was found that taking a **standard supplement** containing the recommended daily dose of vita-

mins (e.g. A, B1, B2, B6, E) and trace elements (e.g. calcium, manganese) improved tear stability[1150].

4.3 Refractive Surgery

Refractive surgeries like PRK, LASIK and LASEK (the basic principle was outlined in section 3.28.1) have become a big industry, and estimates for the USA were 1,900 000 procedures in 2002, up from 465 000 in 1998[1151].

In the USA, "at least" several hundred ophthalmologists had LASIK or PRK for themselves – of about 20.000 ophthalmologists in practice[1152].

Nevertheless, people who are expecting that they are getting rid of glasses or contact lenses by refractive surgery forever should consider:

The rate of **complications** at LASIK was estimated to be at 7.2%[1153] and more recently 2%[1154], and for 11.6% of the eyes were re-treatment was found to be necessary[1155]. Keratitis, an inflammation of the cornea, was observed in 0.7% to 32% of the LASIK treatments[1156]. Bacterial infections appear to be especially a potential problem for persons exposed to a healthcare setting[1157].

On the other hand, it was claimed that the earlier rate of 20% of complications of laser treatment dropped below one percent[1064].

Furthermore, it was said that most problems arise due to a faulty pre-examination and information of the patients[1064].

Some data about the **probability that no more glasses or contact lenses are necessary**: A report states that for -4.25 D up to -8.00 D 86.5% of the patients stayed within 1.00 D of intended correction, and for above -8.25 D 82.9% of the patients stayed within 1.00 D of intended correction.

The **regression** was -0.5 D for patients between -0.5 D and -4.0 D (only during 1st to 3rd month), -0.8 D for patients between -4.25 D and -8.0 D (1st to 6th month), and -1.2 D for patients above -8.25 (1st to 9th month)[1045].

For **follow-up LASIK procedures** to eliminate residual myopia the rate of complications is substantially elevated[1158].

This means, you have a **good chance, to need still some glasses or contact lenses** – which you wanted to get rid of forever.

Additionally, even if myopia is (rather) stable, there are often some moderate changes during the lifetime, which are easy to correct with glasses or contact lenses. And for your presbyopia you need some glasses or contact lenses anyway.

For a group of 1308 patients the one-year **re-treatment incidence** was 12.1% for myopic eyes, with an increase to 14% for patients older than 40 years[1159].

Barclay stated[1159]: "In most cases, LASIK flaps could be lifted using manual technique up to three years after the initial surgery."

Note:
This means the stability of the LASIK-flap is rather limited for quite a long time.

With LASEK this problem does not exist[1160].

There is a serious risk to develop **dry eyes** after the LASIK surgery[1161].

The **climatic environment**, i.e. temperature and humidity, play an important part with respect of the complications associated with LASIK surgery: the colder and the less humid, the better[1162].

Machet stated[1046]: "Just as the good can be very good, the bad can be very bad."

An example of the potential risk of LASIK and similar surgery was the recall of software for a LASIK system as summarized by Waknine[1163]: "The action was based on reports of corneal abnormalities ("central islands") that may not be correctable with laser therapy, according to an alert sent from MedWatch, the FDA's safety information and adverse event reporting program. Use of the algorithms has also resulted in decreased visual acuity that may not be correctable with use of glasses or contact lenses."

Villa reported[1164]: "Patients undergoing LASIK procedures display an **increase of halo phenomena around lights in night vision conditions**, even when the results of the surgery are considered entirely satisfactory according to current international standards of predictability, efficacy and safety. Secondary astigmatism, coma and spherical aberration are the higher order aberrations up to the sixth order that significantly correlated with halo disturbance index."

Obviously, the brand of the equipment for the laser operation still plays a major part, as Feltham reported[1165]: "A successful refractive outcome was achieved in 78% (235/302) of surgeries using the Technolas laser and in 88% (266/302) using the NIDEK laser. Predictor variables for not achieving refractive success were pre-operative refractive error of above -5.00 DS, age more than 40 years, and surgery performed with the Technolas laser."

Some questions you should ask before getting surgery done, are[1166]:

What is your success rate for achieved visual acuity (that is, 20/40 or better)?

How many operations have you performed personally?

May I speak with any of the patients on whom you have done this procedure?

How many of them have required second operations? (It should be under 10%.)

What is the best correction I can expect?

How much will the operation cost me?

What are the chances I may not see as well as with glasses or contact lenses?

Do you operate on both eyes the same day?

What are the possible complications?

What anesthesia will I receive during the operation?

How long will the procedure take?

What is the recovery period?

When will I be able to return to work?

If the operation fails to correct my vision, will I be able to go back to contact lenses?

What if, years from now, I develop cataracts? Will this operation prohibit or interfere with later cataract surgery?

What are the long-term risks of this surgery?

Most refractive surgeons prefer an undercorrection instead of an overcorrection, because this leaves room for later corrections[1167] (maybe you prefer a slight undercorrection because of the presbyopia you might face later, see section 4.2.11).

Generally it is recommended that only **one eye at a time** is operated, to preserve at least the vision of one eye in the worst case of complications.

Refractive surgery is not recommended for people with diabetes, or rheumatic diseases[1168].

For people who had photorefractive surgery like PRK it was found that high dose of vitamin A and E supplementation may accelerate the healing of the cornea and may reduce corneal haze formation[1169].

Candidates of these treatments should be aware, however, that the result of the surgery will not be stable and the myopia will progress if the environemtal conditions which caused the myopia (like excessive nearwork) still persist.

More information about LASIK can be found in the "**Official Patient's Sourcebook on Myopia**"[1170], and in the "**Official Patient's Sourcebook on LASIK Surgery**"[1171] – and in **YouTube**[1172].

4.4 Useful Links

Scientific publications

The United States National Library of Medicine (NLM) maintains a database called MEDLINE of 11 million indexed journal citations and abstracts now covering nearly 4,500 journals published in the United States and more than 70 other countries. MEDLINE includes references to articles indexed from 1966 to the present.

Abstracts of the respective publications can be searched and retrieved via the address:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?CMD=search&DB=PubMed

Full text articles can be bought from a library in your country (sometimes articles can be bought directly by accessing a link which is sometimes shown together with the abstract). Addresses of the respective libraries can be found at:

http://www.nlm.nih.gov/ild/main.cfm (outside United States)

http://nnlm.gov/members/ (United States)

Numerous sources of information about all kind of issues which are related to myopia can be found in: Parker JN, Parker PM (editors), The 2002 Official Patient's Sourcebook on Myopia ("A reference manual for self-directed patient research"), ICON Health Publications, http://www.icongrouponline.com/health

Other sites about myopia and related issues, which are especially worth visiting

http://www.kaisuviikari.com/panacea.htm and
http://www.kaisuviikari.com/books/PANACEA_by_Kaisu_Viikari_1978.pdf
http://www.kaisuviikari.com/book/

http://www.nb.net/~sparrow/myopia.html

http://www.chinamyopia.org/mainenglish.htm

http://www.i-see.org and http://www.i-see.org/otis_brown/

http://www.myopiaprevention.org/action_plan.html

http://dmoz.org/Health/Conditions_and_Diseases/Eye_Disorders/Refractive_Errors/Myopia/

http://members.aol.com/myopiaprev/index.htm

http://www.agingeye.net/myopia/myopiaindex.php

Connective tissue disorder site

http://www.ctds.info/

Organizations in the field of myopia

A record of vision science research institutes worldwide can be found at

http://www.visionscience.com/vsInstitutes.html

Eyes and contact lenses in general

http://www.eyemdlink.com/Condition.asp?ConditionID=131

Some manufacturers of contact lenses or material for contact lenses

Bausch & Lomb: http://www.bausch.com/us/resource/visioncare/

Ciba Vision: http://www.cibavision.com/ and

http://www.cibavision.co.uk

Johnson & Johnson: http://www.jnjvision.com/

Menicon: http://www.menicon.co.jp/english/

Some manufacturers of care products for contact lenses

http://www.allergan.com/sitemap/index.htm

http://www.alconlabs.com/

Refractive surgery

http://drmcdonald.eyemdlink.com/EyeProcedures.asp

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